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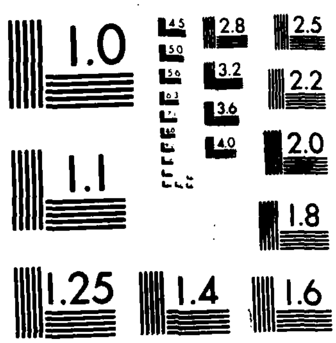

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

A METHODOLOGY TO AID THE COAST GUARD
IN THE DECISION TO PROCURE
OR MAINTAIN TELECOMMUNICATIONS SYSTEMS

by

Michael Dean Inman

June 1986

Thesis Advisor: Kent D. Wall

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This thesis develops a methodology that is designed to aid the Coast Guard decision-maker in the determination of whether to procure a new telecommunications system or maintain a present telecommunications system. The thesis delineates the system cost factors, and the performance measures of the systems that are important for the evaluation of the two systems (present or proposed). An approach is then developed using the cost and performance information, which results in marginal benefit/marginal cost ratios. These ratios become the principal evaluation measures in a multicriteria framework for solving the decision problem. The decision-makers preferences are solicited and integrated with the evaluation measures by employing the Analytic Heirarchy Process. The end result is a recommendation for the preferred system which is based on the correct marginal criteria and incorporates the relevant preferences and implicit trade-offs. This uses "off the shelf" software.

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A Methodology to Aid the Coast Guard in the Decision to Procure or Maintain Telecommunications Systems

by

Michael Dean Inman
Lieutenant, United States Coast Guard
B.S., United States Coast Guard Academy, 1980

Submitted in partial fulfillment of the
requirements for the degree of

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JUNE 1986

Author: Michael Dean Inman
Michael Dean Inman

Approved by: Kent D. Wall
Kent D. Wall, Thesis Advisor

F. Marchman Perry
F. Marchman Perry, Second Reader

Willis R. Greer, Jr. Chairman
Department of Administrative Sciences

Kneale T. Marshall
Kneale T. Marshall
Dean of Information and Policy Sciences

ABSTRACT

This thesis develops a methodology that is designed to aid the Coast Guard decision-maker in the determination of whether to procure a new telecommunications system or maintain a present telecommunications system. The thesis delineates the system cost factors, and the performance measures of the systems that are important for the evaluation of the two systems (present or proposed). An approach is then developed using the cost and performance information, which results in marginal benefit/marginal cost ratios. These ratios become the principal evaluation measures in a multi-criteria framework for solving the decision problem. The decision-makers preferences are solicited and integrated with the evaluation measures by employing the Analytic Hierarchy Process. The end result is a recommendation for the preferred system which is based on the correct marginal criteria and incorporates the relevant preferences and implicit trade-offs. This uses "off the shelf" software.

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I. INTRODUCTION

A. BACKGROUND

This thesis is intended to aid Coast Guard decision-makers and telecommunications managers in the process of determining whether to procure new telecommunications systems or to maintain the systems that are presently installed. As part of the decision process, the decision-maker must decide if the improvements a new telecommunications system provides are worth the capital investment that will be required.

The area of telecommunications procurement is of interest due to the present technological environment, which seems to be changing continuously and, in many situations, at an increasing pace. The Coast Guard like many other organizations, both governmental and private, is feeling pressure to keep up with technology in the telecommunications field, particularly with the increasing cost of personnel required to operate and maintain the older systems. The Coast Guard, however, must operate in an austere budget environment in response to recent congressional initiatives (i.e. Gramm-Rudman) and cannot afford to employ systems that are at the leading edge of technology. This opinion is based in part on the fact that traditionally technology has been at its highest cost when

initially introduced. These costs are even higher if the procuring organization has funded a large percentage of the research and development (R&D) costs. At the same time the reliability of these systems has normally been at its lowest, which has resulted in high maintenance costs. This low reliability (i.e. higher number of failures) when systems are first introduced for operational use is normally due to component variations and mismatches, a non-mature manufacturing process, or in some cases an inmature/unstable technology[Ref. 1: p. 26]. The high failure rates when technologies are initially introduced can be illustrated by the bath tub type curve displayed in Figure 1.1, were the vertical axis is the failure rate and the horizontal axis is time.

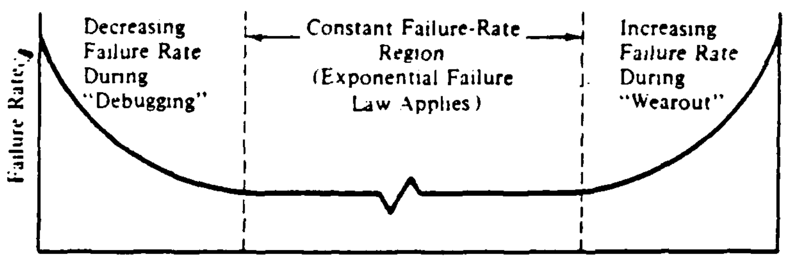


Figure 1.1. Typical Failure-Rate Curve

[Ref. 1: p. 28]

The above discussion, then leaves the question of when is the proper time for Coast Guard managers to procure new telecommunications systems, rather then maintain present systems. As a clarifying point, "procure" does not necessarily mean "buy", it could refer to leasing or contracting for services. This thesis will present a method by which these determinations can be made. The method will be reasonable for Coast Guard telecommunications managers to utilize, and it will be an aid to the decision-maker in this process.

B. AREA OF EMPHASIS

This thesis focuses on shore based telecommunications systems, particularly telephone type systems. With recent innovations in the telecommunications field and the emphasis on using the same telecommunications path ("pipe") for multiple uses, there will naturally be coverage of data communications systems. An attempt, however, will be made to avoid systems that are used exclusively for data communications such as local area networks (LANS). Even with the limited scope of this thesis, many of the techniques and most of information provided should prove helpful when dealing with other telecommunications system procurements.

C. EVALUATION PREMISES

This thesis will develop a cost/benefit comparative approach for determining whether it is the proper time for moving from the presently installed systems to a new system, or if it is more desirable to maintain the present systems for an extended life cycle. This requires comparing the present system against a proposed system. In order to carry out this evaluation there must be two established systems to compare. The present system should, and normally would, have an established specification for its operation and engineering. There remains the establishment of the specification and evaluation criteria for both the proposed system and the existing system.

The determination of the specification for the proposed system would normally be done by writing a proposed operational and engineering specification for the system. This proposed specification would then be routed through the appropriate organizational components to obtain feedback on needed/required changes to the specification, and hopefully a concensus will be reached by staff components on the contents of the specification. This finalized specification should then be approved by the decision-maker.

Once the specification has been approved, the next step in this evaluation process is to communicate informally with industry (whether through telephone communications, the

providing of the specification, or the providing of a draft Request for Proposal (RFP)), to obtain information on those systems that meet the specification, and to establish reasonable cost estimates for the proposed system life cycle. This process may be more formal in that the Coast Guard could synopsize the specification in the Commerce Business Daily, stating the the Coast Guard is looking at replacing a specified system, and those firms that are interested should contact the Coast Guard for the full RFP. Those firms that show an interest would then hopefully submit bids that could be evaluated.

For this thesis, the bid/proposed system that best fits the desired specification (i.e. the system that meets at least the minimum of all requirements) will be evaluated against the present system. If more then one system meets the minimum specification, the Coast Guard (normally the telecommunications manager) must determine which system is to be evaluated against the presently installed system. This might be the system that seems to have the lowest life cycle cost (LCC), or highest performance above minimum specification levels, or any combination that is desired.

Once the proposed system is selected it is then necessary to compare the proposed system against the present system. The comparison of these two systems must be specified for evaluation over a certain time period, i.e. life cycle of operations. This life cycle entails 1)

installing the proposed system and operating it for its life cycle or 2) extending the life cycle of the presently installed system. In the government, the normal life cycle for equipment is considered 10 years, but in this evaluation a life cycle of 5 years will be used. This is due in part to the fact that an extended life cycle for the present system beyond 5 years seems unreasonable, and technology in the telecommunications field seems to be changing rapidly enough that the author feels the actual economic life of many telecommunications systems is in reality only five years.

D. PROCUREMENT AUTHORITY

Throughout the evaluations that are being discussed in this thesis, it is important to remember that for telephone and data communications systems to be procured by individual government agencies, including the Coast Guard, requires Delegated Procurement Authority. In order to obtain Delegated Procurement Authority a request must be made to the General Services Administration (GSA). This implies that whether or not the Coast Guard feels that a new system should be procured, GSA must give its approval for the Coast Guard to go out on its own and procure such systems. The evaluations discussed in this thesis may well help convince GSA of the reasons and needs for the procuring a new system.

E. THESIS OUTLINE

In this thesis as mentioned, a methodology will be developed to aid the Coast Guard decision-maker in the process of determining whether to maintain a present telecommunications system or procure a new system. In order to develop this methodology it is first necessary to explain the thought process behind the development of the methodology. It is felt that in the Coast Guard of today too many decisions are made concerning the procurement of telecommunications systems without the benefit of a proper analysis. This works both ways, in that many system have been procured because, like a new toy, you have got to have it. While on the other hand, systems that should have been procured are not, because too much weight has been given to one concern, i.e. life cycle cost. Therefore the author has developed a methodology that forces the analysis of the system benefits with respect to cost, and this analysis is integrated with the decision-makers subjective judgments concerning the criteria that are considered important, and how the evaluated systems stack up against these criteria.

1. Chapter II

Chapter II, outlines the approach to the development of this methodology. This chapter first discusses the premises on which the developed methodology is based. These are essentially cost/benefit analysis, which involves marginal cost and marginal benefit; cost

effectiveness, which is the determination of how effective a system is without requiring the quantifying of the benefits in dollars, for the dollars that are inputted into the system; the multi-criteria problem, which deals with complex problems, that have multiple criteria of concern; and finally, the decision-maker's preferences, which enable the solving of the complex problem.

The first step in the analysis of any large scale problem involving system procurement is the determining the costs of the systems to be evaluated. Chapter II goes on to discuss the designs of the spreadsheets that will be used to summarize the life cycle costs of the two systems that are to be evaluated. These summary spreadsheets will have information passed to them from lower level spreadsheets, where the actual calculations are carried out. The lower level spreadsheets will not be designed in this thesis, as their designs will vary with the manner in which the different cost categories are determined, and with the particular systems that are being evaluated.

The next step in the development of this methodology is the designing of the spreadsheet that will be utilized to compare the two respective systems. The spreadsheet will include the system life cycle costs and system performance/capability measures, such as number of communications channels, bandwidth for the system's channels, etc.. This spreadsheet will determine the average

costs of the performance/capability measures for each system, and the marginal benefit/marginal cost ratios for the move from the presently installed system to the proposed system. The interpretation of the average cost and marginal benefit/marginal cost ratios will then discussed, to provide the user an understanding of the information the spreadsheet in presenting.

2. Chapter III

Chapter III will outline the system cost factors that make up the life cycle costs of any system from acquisition through its life cycle. The chapter will also discuss equations available and the manner in which they are used to determine the costs that will be inputted into the summary life cycle cost spreadsheets which are discussed in chapter II.

3. Chapter IV

In Chapter IV outlines the system performance/capability measures, that are felt to be important in the decision to maintain the present system or procure a new system. The methods for determining the values for the measures are discussed, as these values would be inputted into the system comparison spreadsheet of Chapter II.

4. Chapter V

The decision methodology will be developed in Chapter V. This methodology integrates the information

provided by the system comparison spreadsheet with the decision-makers subjective judgments of the relative importance of the various criteria (i.e. the performance/capability measures). This will be done by the use of the Analytic Hierarchy Process outlined in Appendix A, as implemented by "off the shelf" software. The decision methodology will enable the decision-maker to determine which is proper, maintain the present system or procure a replacement system.

5. Chapter VI

Chapter VI will then summarize the overall methodology, and present the authors conclusions.

As apparent, from the above discussion the structure of the thesis is one that starts with the overall concept in Chapter II. The component parts are discussed in detail in the chapters that follow.

II. METHOD OF APPROACH

A. SYSTEM EFFECTIVENESS

In this section, the premises upon which the methodology is based will be discussed. These discussions will outline the theory and approach that is utilized in the solving of the decision problem. The areas that will be examined are the following:

a. cost/benefit analysis.

b. cost-effectiveness analysis.

c. the multi-criteria problem.

d. decision-makers preferences.

1. Cost/Benefit Analysis

Cost/benefit analysis is based in general on the terms of industry, were the goal of firms is to maximize profit. Therefore, when a firm carries out analysis to determine whether another dollar inputted into a program, such as an advertising budget, is desirable it will normally look to see if the benefits derived (i.e. revenue) increase. The basic principle of profit maximization is fairly simple.

> A firm will increase any activity so long as the additional revenue from the increased activity exceeds the additional cost of the increase in activity. The firm, on the other hand will cease to expand the activity if the additional revenue is less than the additional cost [Ref. 2: p. 44].
>
> As the firm increases its output, each additional output produced and sold adds to the total revenue of the firm.

> The change in revenue per unit change in output is called marginal revenue. As the firm increases its level of output, each unit increase in output also increases the firms total cost. The additional cost per unit increase in output is called marginal cost[Ref. 2: p. 44].

In the case of the government, the goal is not to maximized profit, but is to serve the taxpayer. For the industrial firm revenue is the benefit that is derived from the input of money. For those cases where profit is not the motive or concern, the term marginal benefit is uses versus marginal revenue. Marginal benefit is therefore defined as the change in the benefit derived per the unit change in input (i.e. dollars). The benefit derived can be anything that is perceived as beneficial, such as communications channels, hours of failure free operations, etc.[Ref. 2: pp. 44-48]

The principle of cost/benefit is as follows:

> An optimizing decision maker will always choose that level of activity where the marginal benefit from the activity equals the marginal cost[Ref. 2: p. 47].

This relationship can be displayed by Figure 2.1.

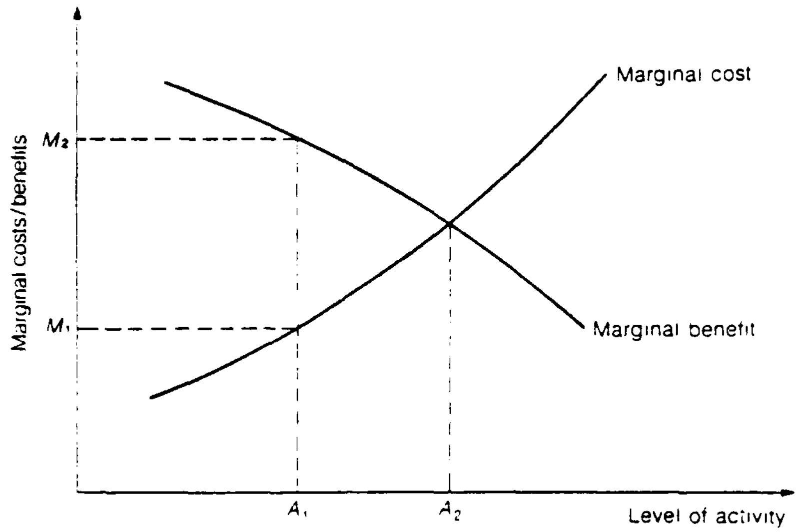


Figure 2.1. Principle of Optimization.

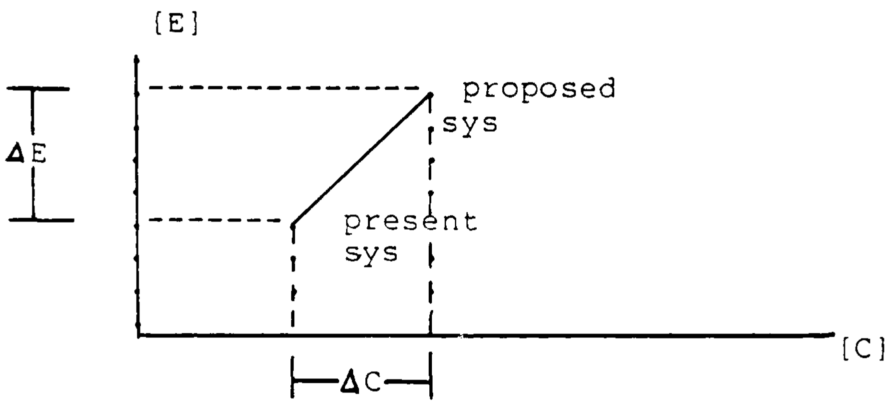
The relationship can also be described by the equation : MC = MB. The benefits derived from a system are not easily quantified, but are dependent on the person(s) that are receiving or will receive the benefits. In this thesis a way will be developed to determine and carry out cost/benefit analysis to determine if the marginal benefit of moving to a new system is equal to the marginal cost.

2. Cost-Effectiveness Analysis

Cost-effectiveness analysis deals with the determination of how effective a system or activity is without requiring that one quantify the benefits in dollars, for the dollars inputted. In terms of the Department of Defense, it is referred to as the "bang for the buck".

Normally, this type of evaluation is done to compare systems, such as an old (presently installed) one and one of several proposed replacement systems. This evaluation gives as a result, the change in an effectiveness measure (Δ E) per change in dollars inputted or cost (Δ C) in a comparison of a proposed system to a present system, for a single effectiveness criterion. This relationship is shown by Figure 2.2. The effectiveness criteria can be any measure, such as communications channels, man-hours in overhead, etc.

The decision-maker attempting to determine which is the most effective system for this single criteria determines if the $\Delta E/\Delta C$ curve/line is "steep enough", in comparison to their subjective judgments.



Where;

ΔE = Marginal Benefit (MB)
ΔC = Marginal Costs (MC)
Slope of Line = $\dfrac{\Delta E}{\Delta C} = \dfrac{MB}{MC}$

Figure 2.2. Cost-Effectiveness Curve.

It follows from a sense of what he/she is willing to pay for the increase in the effectiveness measure. This can be explained by Figure 2.3, where in case 1 the decision-maker is willing to pay more for a lesser increase in the effectiveness measure. Therefore, the proposed system would be accepted. In case 2, however, the decision-maker desires to obtain a greater change in the effectiveness measure for a lesser increase in the cost. Therefore, the proposed system is rejected, and the present system would be maintained. The manner in which the decision makers preferences can be determined will be discussed later.

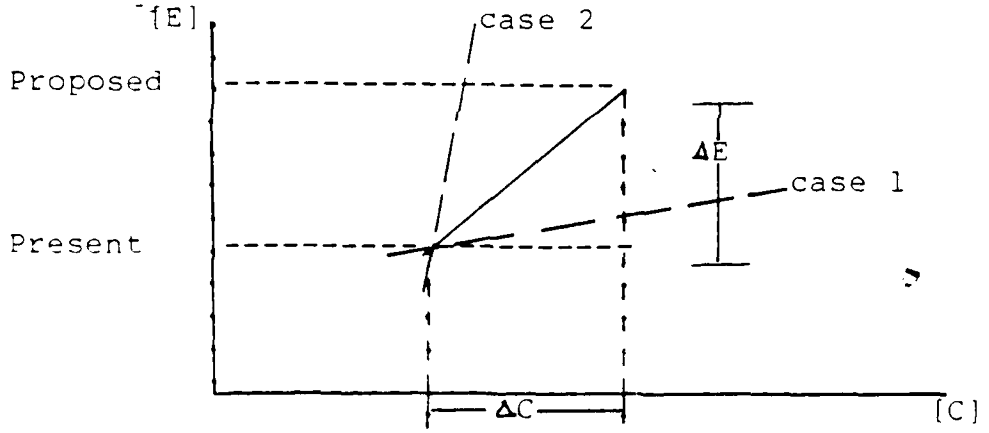


Figure 2.3 Effect of Decision-Makers Judgments

3. <u>The Multi-Criteria Problem</u>

Many times when dealing with complex problems, there are multiple criteria. In the case where we have [illegible] criteria, say cost and two effectiveness [illegible], Figure 2.2 would be replaced by Figure [illegible] find a method that will allow [illegible] of $\Delta E_1 / \Delta C$ and $\Delta E_2 / \Delta C$.

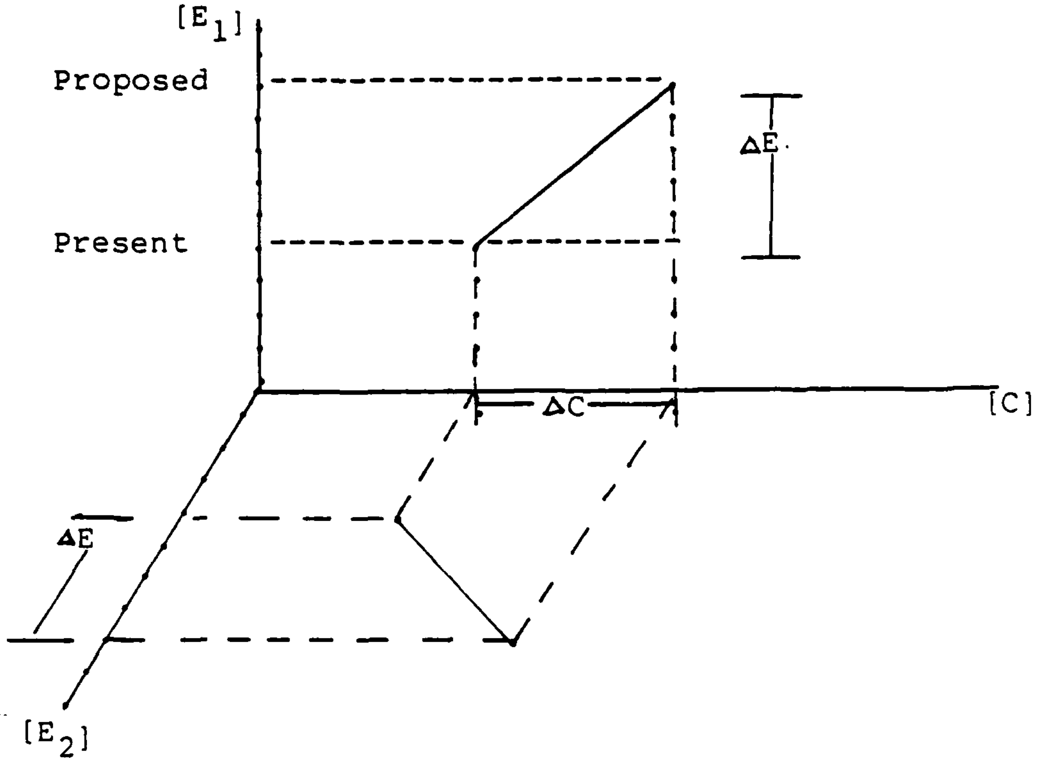


Figure 2.4. The Multi-Criteria Problem.

4. Decision-Makers Preferences

The multi-criteria decision problem would be solved if we had an explicit statement of the decision-makers preferences so the appropriate trade-off between $\Delta E_1/\Delta C$ and $\Delta E_2/\Delta C$ could be computed. It would then be possible to establish the proper weighting for the various E/ C ratios. This would then allow the aggregation of the various $\Delta E/\Delta C$ ratios into one ratio, so that the multiple criteria are reduced to the classical single-criteria trade-off, thus enabling the consideration of all the various criteria, in order to obtain the proper solution for the decision.

In this thesis, we will utilize "off the shelf" computer software to elicit the preference information of

the decision-maker for the various criteria, and with respect to these criteria the decision-maker's preferences for each of the possible solution alternatives. This will be done by the use of the Analytic Hierarchy Process due to T. Saaty, as implemented by the commercially available "Expert Choice" software.

5. Summary

In the remainder of this thesis the elements of a solution procedure will be integrated into a methodology that will enable a decision-maker to rationally determine whether to maintain the present telecommunications system or procure a new telecommunications system.

The first step in the solution of the outlined decision problem is the development of templates for spreadsheet presentations of all the relevant information for the decision problem. The three major spreadsheets that will be developed are life cycle cost for the extended life cycle of the present system, life cycle cost of the proposed system, and finally a spreadsheet that displays the system comparisons, where the life cycle costs are integrated with the effectiveness criteria to produce the ratios as discussed above.

The next step will be to integrate the information provided by the above spreadsheets into a multi-criteria decision making (MCDM) methodology. This will be done in order to give the decision-maker the ability to consider all

the criteria in the solution of the decision problem. For this step the Expert Choice software implementation of the Analytic Hierarchy Process will be used.

B. SPREADSHEET FOR PRESENTATION OF COST INFORMATION

1. The Spreadsheet

In order to make this methodology as applicable as possible for Coast Guard use, the spreadsheet being used for this evaluation is the software that is resident on the Coast Guard standard terminal. The Coast Guard standard terminal is the C3 micro-computer, manufactured by Convergent Technologies, utilizing the CTOS operating system. The spreadsheet software resident on Coast Guard C3 configurations is Multiplan version 8.2, a product of Microsoft Incorporated.

Multiplan is a computer software tool designed to aid the user in the analyzing of data. Multiplan is considered a powerful tool in modeling and planning efforts, and is extremely useful in any accounting type effort. The Coast Guard is presently using Multiplan extensively for financial type applications. The Multiplan software is toted as easy for just about any user to learn, and from the authors personal experience, with a reasonable effort on the users part it can be learned and effectively used after only a few hours of training.

In this chapter, Multiplan's usage will be explained as it applies to the maintain or procure decision. It is felt that with the aid of the Multiplan user manual, the reader will have little trouble developing this methodology for their specific application. The Multiplan spreadsheet is a worksheet of row and columns that allows the designing of an accounting style spreadsheet, of just about any size, from the very small (less than a 8 1/2 X 11 sheet) to the extremely large. The display on the computer terminal CRT provides a command menu, that covers just about any aspect of the spreadsheet usage. The help command will aid in the answering of any question that may come up during the use of Multiplan.

Two features that prove very useful in the design and use of spreadsheets are the ability to develop formulas for cells by moving the cursor to the cells that will be utilized in the formula, whether multiplication, addition, subtraction, or division of the various cells is to be done to obtain the desired outcome, i.e. the specified formula in the desired cell. The other feature is the ability of Multiplan to link data between different spreadsheets, which proves very useful in the methodology to be developed.

2. Present System Costs

In order to develop the costs for an extended life cycle of the presently installed system a spreadsheet will be developed that covers the costs to the system as outlined

in chapter III. The assumption may be made that acquisition of additional equipment will not be required to obtain this extended life cycle. The cost categories will be broken down by year. The extended life cycle will be for five years, as extending the life cycle beyond this point does not seem practical as discussed in Chapter I. The overall life cycle costs will then be summed for this given period of years. The yearly sums and life cycle sums will then be discounted to obtain values of these costs, and net present costs of the systems in dollar values for the period of the evaluation.

a. Design of the Spreadsheet

The designing of this spreadsheet shall be carried out to provide a clear, concise display that the telecommunications manager, and decision-maker will be able to view and have an understanding of the costs in the various areas that contribute to the overall cost of an extended life cycle. The display will be similar to the spreadsheet format displayed in Figure 2.5.

Presently Installed System Cost Estimates for Extended Life Cycle

	Year1	Year2	Year 3	Year 4	Year 5	Lcc summation
Operating and Maintenance Personnel Costs						
Administrative and Supply Personnel Costs						
Personnel Retraining Costs						
System Personnel Costs	$0.00	$0.00	$0.00	$0.00	$0.00	
Energy Consumption Costs						
Material Consumption Costs						
Repenishment Spares and Repair Material Costs						
Inventory Administration Costs						
Transportation Costs						
Support Equipment Maintenance Costs						
Maintenance Facilities Costs						
System Operations Costs	$0.00	$0.00	$0.00	$0.00	$0.00	
Yearly System Costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Discount Factors (Discount Rate=10%)	1	0.9091	0.8265	0.7513	0.683	
Yearly Discounted System Costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Undiscounted Life Cycle Cost	$0.00					
Discounted Life Cycle Cost	$0.00					

Figure 2.5. Present System Cost Spreadsheet

From viewing this spreadsheet, it should be clear that this spreadsheet is a summary of the costs per year in each category, and not the place where these costs would actually be determined. This is done to maintain the conciseness of the spreadsheet. The estimating equations and results should be determined on another spreadsheet, with the results linked/copied to this spreadsheet. This can be done automatically be the use of the Multiplan External Copy command. The design of the actual accompanying spreadsheet

will be left to the user to design, as there are numerous choices of equations for the various categories as will be outlined in Chapter III. By not providing this information on the summary spreadsheet, hopefully will alleviate the problem of providing the decision-maker with more information then is comprehendable, or in many case necessary for the decision process. If the decision-maker becomes concerned with the way estimates are obtained for the various cost categories, the complementing/linked spreadsheet could be provided. The definition and description of each category in the spreadsheet will be provided below, with any internal formulas that are contained within the spreadsheet.

(1) Operating and maintenance personnel costs. This category under the operating and maintenance of the system, includes the costs of personnel that are required to operate the system, and maintain the system at all levels of repair that are established (i.e. unit lever repair, intermediate level repair, depot level repair). This value will be obtained from the complementing/linked spreadsheet. This value will be obtained by the use of the formulas outlined in chapter III.B.1.

(2) Administrative and supply personnel costs. The administrative and supply personnel costs are those costs that occur due to personnel overseeing and directing the operation of the system, those responsible for

consumable materials, spares, and replacement parts being available, and those personnel that are concerned with budgeting matters as they relate to the system. Again, these values will be obtained by the use of equations outlined in chapter III.B.4., from the complementing/linked spreadsheet.

(3) Personnel retraining costs. The personnel retraining category involves those costs required to insure that trained personnel are available to operate and maintain the system and equipment of interest. These costs are covered in chapter III.B.7., and will be obtained from the complementing spreadsheet that will be linked to the present system LCC sheet.

(4) System personnel costs. The system personnel cost category is a summation of all personnel costs related to the present system. This category is a summation of operating and maintenance personnel, administrative and supply personnel, and personnel retraining costs. The category is summed on a yearly basis for the extended life cycle of the system.

(5) Energy consumption costs. The energy consumption category relates to those costs that are required to insure power is provided in order for the system to operate, which normally in the telecommunications field is electrical power. This value will be obtained by the use of the formulas outlined in chapter III.B.2.

(6) Material consumption costs. Material consumption costs are those costs related to the consuming of such things as paper, typewriter ribbons, magnetic tape, etc.. These costs are outlined in chapter III.B.3.

(7) Inventory administration costs. Inventory administration costs are those costs involved in the management and holding of inventory, and the supporting of technical data. These costs and possible estimating equations are discussed in chapter III.B.6., and will be obtained from the complementing/linked spreadsheet.

(8) Transportation costs. This category covers the costs that are incurred from the shipping of material that is related to the operation and maintenance of the system. These costs are discussed in chapter III.B.8.

(9) Support equipment maintenance costs. Support equipment maintenance costs are those costs that are incurred in order to maintain equipment that is used to insure the operation of the system. Support equipment normally includes test and diagnostic equipment, and hardware repair items, such as drill presses, lathes, etc. These type costs are discussed in chapter III.B.9.

(10) Maintenance facilities costs. Maintenance facilities costs are those costs required to maintain a repair facility, such as building maintenance and painting, grounds maintenance, heating and air conditioning, and electricity. These costs are normally absorbed into the

$$\text{DISCOUNT FACTOR} = \frac{1}{(1 + R)^n}$$

Where;

R = Interest Rate/ Discount Rate

n = Year

In this application, the assumption is made that costs are paid at the beginning of each year. Therefore, n=0 for year 1, and the discount factor is equal to 1. A discount rate of 10% is normally used, as this is required for all government evaluations. This makes the assumption that the real interest rate for the government, independent of inflation is 10%.

(14) Yearly discounted systems costs. The yearly discounted systems costs are the yearly system costs after the appropriate discount factors have been applied. A summation of the life cycle costs in this category is provided under the column labeled LCC Summation, which has the discount factors applied.

(15) Undiscounted life cycle cost. The undiscounted life cycle costs is the summation that was developed in the yearly system costs category.

(16) Discounted life cycle cost. The discounted life cycle cost is the summation that was developed in the yearly discounted system costs category.

overhead of the Coast Guard, unless the facility is dedicated to a particular system. These costs are discussed in chapter III.B.8.

(11) Systems operations costs. This category is the summation of all costs related to the O&M of the system, excluding personnel costs. The system operating costs summation includes energy and material consumption costs, replenishment spares and repair material costs, inventory administration costs, transportation costs, support equipment maintenance costs, and maintenance facilities costs, under the column labeled "LCC summation"

(12) Yearly system costs. This category is the summation of all system operating and maintenance costs, and is found by the addition of system personnel and system operations cost categories. This category also includes a summation of the undiscounted life cycle cost for the extended life of the present system.

(13) Discount factors. Discount factors as applied to this spreadsheet have the normal conotation of what future costs are worth in dollars at the time of the evaluation, i.e. net present value. A discount factors that are used for each year are determined by the following equation:

3. Proposed System Costs

To develop the life cycle costs for the proposed replacement system, a summary spreadsheet will be developed that is similar to the one developed for the presently installed system. And again, the summary spreadsheet of costs will be linked to a complementing spreadsheet, where actual calculations of the values for the various categories contained on the summary sheet will be carried out. The design of this complementing spreadsheet is dependent on the individual user's decisions as to the equations that are deemed appropriate for use.

a. Design of the Spreadsheet

The basic design of the spreadsheet for the proposed system life cycle costs will be the same as that for the presently installed system, with the exception that categories for system acquisition and installation have been added. A sample of the spreadsheet design for the proposed system is shown by Figure 2.6.

Proposed System Cost Estimates for Life Cycle

	Year1	Year2	Year3	Year4	Year5	LCC summation
Basic Equipment Costs						
Initial Spares and Repair Parts Costs						
Initial Personnel Training Costs						
Peculiar Support and Test Equipment Costs						
Site Preparation Costs						
System Engineering and Design Costs						
Initial Technical Data and Documentation Costs						
System Acquisition and Installation Costs	$0.00	$0.00	$0.00	$0.00	$0.00	
Operating and Maintenance Personnel Costs						
Administrative and Supply Personnel Costs						
Personnel Retraining Costs						
System Personnel Costs	$0.00	$0.00	$0.00	$0.00	$0.00	
Energy Consumption Costs						
Material Consumption Costs						
Replenishment Spares and Repair Material Costs						
Inventory Administration Costs						
Transportation Costs						
Support Equipment Maintenance Costs						
Maintenance Facilities Costs						
System Operations Costs	$0.00	$0.00	$0.00	$0.00	$0.00	
System Operations and Maintenance Costs	$0.00	$0.00	$0.00	$0.00	$0.00	
Yearly System Costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Discount Factors (Discount Rate=10%)	1	0.9091	0.8265	0.7513	0.683	
Yearly Discounted System Costs	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Undiscounted Life Cycle Cost	$0.00					
Discounted Life Cycle Cost	$0.00					

Figure 2.6. Proposed System Cost Spreadsheet

Due to the similarities in design between the presently installed and proposed system spreadsheets, only the system acquisition and installation category definitions will be provided below.

(1) Basic equipment costs. The basic equipment costs category will include all costs that are incurred in the procurement of the prime equipment, and accessories for the proposed system, that are required for the system to operate to the developed specifications. This information on the summary sheet will be obtained from a complementing/linked spreadsheet that will be used to determine and display all the relevant cost categories. Again, the design of this spreadsheet will be left to the user, as the formulas and methods to determine the costs in the various categories are numerous, and their usage will vary depending on the system being evaluated, and the information available.

(2) Initial spares and repair parts costs. This category is concerned with the costs that are incurred when initially provisioning a system with spares and other repair material parts, to insure the operations of the system for a specified time period. These costs are discussed in some detail in chapter III.B.2.

(3) Initial personnel training costs. Normally, when procuring a new system or a group of equipment, some amount of training is required for the Coast

Guard to operate and maintain the equipment properly. This category is to provide the costs that will be incurred if the proposed system was to be procured. These costs are discussed in chap III.A.3.

(4) Peculiar support and test equipment costs. Peculiar support and test equipment costs are those costs associated with the procurement of specialized equipment that is necessary to support and maintain a system. The equipment is assumed to not already be in the Coast Guard's inventory of equipment. These type costs are discussed in some detail in chapter III.A.4. The values for this category will again be obtained from a complementing/linked worksheet.

(5) Site preparation costs. This category covers the costs that would be incurred for preparing a Coast Guard facility or site for receiving the proposed system, if it was to be installed. The type items that will be covered are construction/destruction of a segment of the facility, the providing of electrical power, lighting, air conditioning and heating hardware, etc.

(6) System engineering and design costs. System engineering and design costs are those costs that would be necessary to insure that the proposed system would have the ability to meet any Coast Guard or government peculiar standards.

(7) Initial technical data and documentation costs. This category is the expenditures that would be required to procure/obtain the initial technical data and documentation that the Coast Guard would determine as necessary to operate and maintain the system.

(8) System acquisition and installation costs. The system acquisition and installation cost category is a summation of all costs related to the acquiring and installing of the system. These costs are the basic equipment, initial spares and repair material, initial personnel training, peculiar support and test equipment, site preparation, system engineering and design, and initial technical data and documentation costs.

C. THE SPREADSHEET FOR COMPARISON OF THE SYSTEMS

The last major step in the development of the basic methodology, is the combining of the life cycle costs of the respective systems, with the performance/capability measures on to a single spreadsheet. This spreadsheet is intended to provide the decision-maker with sufficient information to make an informed decision, when faced with a problem involving multiple criteria. These criteria are those that the decision-maker will be concerned with in a decision to maintain a presently installed system, or to procure a replacement system.

The goal of the system comparison spreadsheet is to provide sufficient information for any decision-maker, no-matter what their background, or personnel biases, to make an informed decision . In order to do this the discounted life cycle costs for both systems are linked to this spreadsheet, as are the performance and capability measures to be used in the comparison of the two systems. The performance and capability measures that will be discussed in Chapter IV., are linked from a complementing spreadsheet that is used to determine the values of each performance/capability measure, as was done with each cost category for the life cycle costs.

1. Design of the Spreadsheet

This spreadsheet has been designed with two major parts to display the most information possible concerning the relationships of the criteria in the clearest possible manner. The lower half of the spreadsheet displays the values for the LCC's, and performance/capability measures that are obtained from the complementing/linked spreadsheets. The upper half of the spreadsheet displays the average costs, and marginal benefit per marginal cost for those criteria in which it is deemed appropriate and useful to do so. The average costs that are displayed are determined by taking the life cycle cost (LCC) of the respective system, and dividing it by the respective performance/capability measure, for example LCC/communications channels.

The marginal benefit/marginal costs ratios that are displayed are determined by the use of data from both systems that are being examined. The basic formula that is being used to determine the marginal benefit (MB)/marginal cost (MC) ratio is as follows:

$$\frac{MB}{MC} = \frac{\text{Proposed System Performance/Capability Measure} - \text{Present System Performance/Capability Measure}}{\text{Proposed System LCC} - \text{Present System LCC}}$$

A sample of the designed spreadsheet is displayed in Figure 2.7.

System Comparisons

Effectiveness Measures	Installed System Average Costs	Marginal Benefit/ Marginal Cost	Proposed System Average Costs
Communications Channels	0 $/channel	0.0000 channels/$	0 $/channel
System Reliability (MTBF/MTBM)	0 $/MTBF	0.0000 MTBF/$	0 $/MTBF
Bandwidth	0 $/BW	0.0000 BW/$	0 $/BW
Ease of reconfiguration	0 $/multi route or backup	0.0000 multi route or backup/$	0 $/multi route or backup
Life Cycle Costs	$0.00		$0.00
Communications Channels			
System Reliability (MTBF/MTBM)			
Man-Hours in Overhead			
Savings in User Man-Hours			
Bandwidth			
Ease of Reconfiguration			

Figure 2.7. System Comparison Spreadsheet

The spreadsheet has integrated into it the following criteria.

a. Life Cycle Costs

Life cycle costs are the costs of the systems over their respective life cycles, in dollars discounted to the present value at the time of the evaluation.

b. Communications Channels

Communications channels are the number of communications channels/paths that a system provides for transmission of communications. An example would be the number of telephone extensions a PBX (Private Branch Exchange) offers for internal use.

c. System Reliability

System reliability is the measure of how much the systems can be relied on to operate as specified. As a measure of system reliability in this examination mean time between failure (MTBF) or mean time between maintenance (MTBM) are used, both measured in hours.

d. Man-Hours in Overhead

Man-hours in overhead is a measure of the time required of Coast Guard and/or contractor personnel to maintain and support a system, to insure that it is in a fully operational condition. The measure is in hours.

e. Savings in User Man-Hours

Savings in user man-hours is a measure of the hours of system users time that would no longer be required

to be dedicated to communications, or use of the communication system, if the proposed system is installed.

f. Bandwidth

Bandwidth refers to the usable bandwidth in kilohertz (Khz) that is available for the transmission of communications. The usable bandwidth directly effects the speed at which communications/information can be transmitted.

g. Ease of Reconfiguration

Ease of reconfiguration is a measure of the ability of a system to operate if and when failures occur within the system. For this examination as a measure of ease of reconfiguration the mean number of multiple routes and/or backup equipment units available per communications channel will be utilized.

2. Average Costs and Marginal Benefit/Marginal Cost Ratio

To provide the reader and user of this methodology an understanding of the information that can be gleamed from the upper half of the system comparison spreadsheet, and how it can be used in the procure/maintain decision, the following discussion of average cost and the marginal benefit/marginal cost ratio are provided.

a. Average Cost

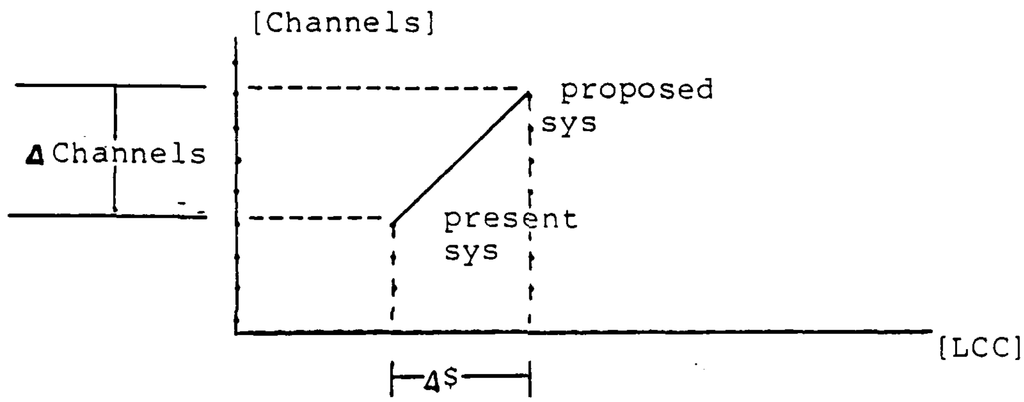
For those performance/capability measures that are included in the upper half of the system comparison

spreadsheet, the average costs that are provided will prove useful to the decision-maker when they are going through the process of determining whether a replacement system should be procured, or the present system should be maintained. The average cost as used in this application provides the mean costs per unit of a performance/capability measure, over the life cycle of each system that is being examined. This measure is independent of any of the other performance/capability measures that also have average costs provided. The average cost provides the manager and the decision-maker with an idea of the cost per unit of performance/capability that is being provided, or will be required, in order to operate a system within the desired capability. For example, the average cost for communications channels has units of dollars ($) per channel, this tells the decision-maker the cost per channel for each system, at their respective channel capacities over the life cycle of each system.

b. Marginal Benefit/Marginal Costs (MB/MC) Ratio

This marginal benefit per marginal cost ratio provides information that is relevant to the moving from the present system to the proposed replacement system. Marginal benefit is thought of as the benefit that is derived by the user/owner, if one more unit (or group of units) of an item is provided, or the reduction in benefit if one item is removed. The marginal cost is considered the cost of adding

one more unit (or group of these units). On the system comparison spreadsheet, what is displayed is the marginal benefit (such as communications channels) divided by the marginal cost for the move from the present system to the proposed system. This ratio is in actuality the slope of the curve/line between the two systems, with respect to the performance/capability measure, such as communications channels and the life cycle cost (in discounted dollars). This relationship is shown by Figure 2.8 below:



Where;

$$\Delta \text{Channels} = \text{Marginal Benefit (MB)}$$
$$\Delta \$ = \text{Marginal Costs (MC)}$$
$$\text{Slope of Line} = \frac{\Delta \text{Channels}}{\Delta \$} = \frac{MB}{MC}$$

Figure 2.8. MB/MC Ratio Curve

Then in the case of communications channels the MB/MC ratio provides information on the communications channels gained per dollar inputted into the life cycle cost. This same derivation could then be repeated for all the performance/capability measures under consideration. It should be noted that man-hours in overhead and savings in

user man-hours are not include in the upper half of the system comparison spreadsheet. The decision-maker would examine the lower half of the spreadsheet. He/she would then go through the same derivation as for the MB/MC ratios in the upper half of the spreadsheet, and determine the savings in dedicated man-hours per dollar inputted into the life cycle costs, for both the operations and use of the telecommunications system.

We now have discussed the general approach to the development of this methodology, the design of the two system cost spreadsheets, and the design and interpretation of the system comparison spreadsheet. In the next chapter, we will examine in detail the system cost factors that are contained in the bodies of the system cost spreadsheets, and the ways available to determine the values for these cost categories.

III. SYSTEM COST FACTORS

This chapter will examine the costs that are prevelant in the development and operation of a telecommunications system over its life time. Normally, the above are combined into a single measure referred to as the system's life cycle cost (LCC). For systems procured in the government sector (and many private sector companies) life cycle cost (LCC) involves the following areas:

(a) Research and Development (R&D) Costs-the cost of feasibility studies; system analysis; detailed design and development, fabrication, assembly, and test of engineering modes; initial system test and evaluation; and associated documentation.

(b) Production and Construction Costs-the cost of fabrication, assembly, and test of operational systems (production models); operation and maintenance of the production capability; and associated initial logistic support requirements (e.g., test and support equipment development, spare/repair part provisioning, technical data development, training, entry of items into the inventory, facility construction etc).

(c) Operation and maintenance Costs-the cost of sustaining operations and maintenance support, spare/repair parts and related inventories, test and support equipment maintenance, transportation and handling, facilities, modifications, and technical data changes.

(d) System Retirement and Phase-out Costs-the cost of phasing the system out of the inventory due to obsolescence or wear out, and subsequent equipment item recycling and reclamation as appropriate.[Ref. 1: p 19]

Within the scope of this thesis, i.e. shore based telecommunications systems, and the Coast Guard's procurement practices for telephone and data systems, the Research and Development (R&D) Costs will not be considered a major cost factor in determining whether to maintain the present system or procure a new system. This is due in part to the fact that the majority of shore communications equipment/systems that the Coast Guard would be interested in would be "off the shelf". The majority of R&D cost for the Coast Guard will be for the examination of system capabilities to see if it fits the service's needs, and the system engineering/design to insure it fits the required architectures of the Coast Guard and of the government.

The cost of System Retirement and Phase-out should have a minor impact on this examination, as the author has made the assumption that the majority of telecommunications systems are at the end of their economic life cycle and have little or no salvage value. This is based on the fact that in areas of rapidly improving or advancing technology (such as micro computers), most consumers/users are not willing to settle for buying some one else's old system. The other area in the Phase-out that may actually represent a cost to the Coast Guard is the removal of old system items such as spares, repair parts, etc. from inventory. These will be considered minor costs.

In summary, this thesis will focus on Production and Construction costs, specifically acquisition and installation costs, and the Operations and Maintenance (O&M) Costs of the systems. The examination of acquisition and installation costs will be limited to the system that is being considered as replacement for the presently installed system.

The acquisition and installation costs will relate to the following areas:

a. Basic equipment procurement.

b. Initial spares and repair parts procurement.

c. Initial maintenance personnel training.

d. Peculiar support and test equipment procurement.

e. Site preparation.

f. Any system design or engineering required to meet Coast Guard/Government peculiar needs.

g. Initial technical data and documentation procurement.

h. Transportation costs.

The Operations and Maintenance (O&M) Costs will look at:

a. Operating and maintenance personnel (including different levels of repair) costs.

b. Energy consumption costs.

c. Material consumption costs.

d. Administrative personnel costs.

e. Replenishment spares and repair material costs.

f. Inventory Administration and management costs.

g. Transportation costs.

h. Personnel training/retraining costs.

i. Maintenance facilities costs.

j. Support equipment costs.

A. ACQUISITION AND INSTALLATION COSTS

1. Basic Equipment Procurement

The basic equipment procurement costs will normally be developed after the decision is made on what the equipment specification are to be, and the quantities required to replace the present system in kind or provide the desired mission by an alternate method. Therefore, the development of this cost category is determined by the costs of basic equipment items required, which are then multiplied by the number of each basic item required. These costs are then summed to determine the overall basic equipment costs.

2. Initial Spares And Repair Parts Procurement

Normally, when first obtaining a new system the practice is to obtain spare units and other repair parts for a specified time period. The above time period will be assumed to be for the first year of system operation. In most cases the number of spare units of basic equipment, and repair parts, such as fuses, circuit boards, etc, will be dependent on the level at which repairs will be carried out on the system, and its components. The possible levels of repair are at the organizational level, intermediate level, depot level. Also options of discarding components upon

failure will be considered. Organizational repair refers to repairs that are carried out at the location of the equipment by the owners/custodians of the equipment. In the Coast Guard when dealing with shore based telephone systems this has normally been limited to 1) replacement of the entire basic equipment component upon failure, and having the basic equipment repaired at a different level, or 2) replacement of failed boards and having the boards repaired at a different level or discarded.

Intermediate level repair in the Coast Guard is normally carried out at ESM's (electronics shop major), or ESMT's (electronic shop and minor telephone). These shops normally limited their repair to basic equipment repair, and major sub-component repair/replacement, but normally very little board repair.

Depot repair in the Coast Guard is normally limited to repair by the manufacturer, either via Supply Center Brooklyn or the manufacturers supply source directly. In telecommunications systems integrated circuitry on boards is becoming more prevelant, because of this repairs beyond board or module replacement at the organizational and intermediate level is becoming less and less common. Due to this, particularly for telephone systems, module and component repair is being limited to depot repair or discard depending on the costs of the individual components and the turnaround time from a depot (i.e. the manufacturer).

Anotner factor that may effect the level of repair strategy is if the Coast Guard is going to provide hot/cold standby equipment at a equipment site, to obtain the desired reliability level, which will effect the number of spares of basic equipment required, and where repair capabilities will be required. An example would be providing a hot standby at a micro-wave link station. This would most likely mean that at the organizational level (i.e. on site), the repair would be limited to replacement of the basic equipment. On the other hand, the costs to provide a hot standby PBX (private branch exchange) might be too expensive, in which case the level of repair would be board/module swap out at the organizational level.

The mean time between failure would also have an effect on the number of spares required. After the system engineering determinations are made on what spares and repair components are to be provided to different locations, it is then possible to determine the initial spares and repair parts costs by the following:

$$\begin{array}{l} \text{Initial Spare} \\ \text{and Repair} \\ \text{Cost} \end{array} = \begin{array}{l} \text{(Cost of Spares)x} \\ \text{(Required Maintenance Actions)x} \\ \text{(Mean Repair Time)x} \\ \text{(Number of Cperating Units)} \end{array}$$

Where

$$\begin{array}{l} \text{Required} \\ \text{Maintenance} \\ \text{Actions} \end{array} = \frac{\text{(Operating Hours)X(Operating Units)X (Quantity of Part/Operating Unit)}}{\text{MTBF}}$$

And

MTBF = Mean Time Between Failures (in hours).[Ref. 3: p. 21]

3. Initial Maintenance and Administrative Personnel Training

When installing a new system, it normally requires unique training for personnel (including operational, administrative, and maintenance), unless the equipment is very similar in technology and design to the equipment that it is replacing or the equipment manufacturer provides system operating and maintenance manuals that can act as tutorials for organizational personnel. This initial training can be provided by the equipment manufacturer, or a third party organization.

In order to establish/determine the cost of initial training it will first be necessary to determine the number of personnel that will require any such training. There seems to be several manners in which to carry this out, depending on the number of each components procured, their geographic distribution, the level of repair and operation responsibilities, and the number of personnel involved/assigned to operation and maintenance of the system of interest. The number of personnel required will normally be established by the Coast Guard Staffing Standard Manual (COMDTINST M5312.11). Once the number of members that will be involved in the operation and maintenance of the system

has been determined, it should be a fairly simple evolution to determine the cost for initial training. Many times the contractor/manufacturer will provide costs for formal on-site training. If off-site formal training is used, travel and per diem must be included in the training costs. If training cost estimates are not available at the time of evaluation, a possible source of estimates for telephone/data system training costs is DCA Circular 600-60-1 (DCA Cost and Planning Factors Manual).

A consideration that should be brought up at this point is OMB circular A-76, which involves the contracting/civilianization of services that have traditional been carried out by military personnel. Telephone related systems are an area that very much fit into this category, since the Coast Guard really does not have the personnel base to maintain trained personnel and telephone/data systems are becoming more sophisticated. Therefore, a proposed project may very well have minimal training requirements as the maintenance and much of the operation of the system may be contracted out. However, these costs must also be considered.

4. Peculiar Support and Test Equipment Procurement

There are some telecommunications systems that may be procured that will require support and test equipment that is either peculiar to the basic equipment or not already in the inventory of units that may be required to

carry out repairs. In order to determine the costs to the organization for support and test equipment, it is first necessary to determine what are the support and test equipment items that will be required for the proposed system. Then it is necessary to determine the units requirements for the above support and test equipment, and what items are already in the inventory. It should then be a simple task of summing the costs of the equipment required.

There may be times that the above procedure is not possible, as sufficient information is not available to determine the actual peculiar support and test equipment costs. In this case the solution is to use a planning factor manual, such as DCA Circular 600-60-1 to estimate the costs. The procedure is based on estimating the cost as a factor of the prime equipment cost such as .10 for test and common support equipment, and .10 for peculiar support equipment (for the system).[Ref. 4: p. 17-3] This then enable the determination of an estimate for peculiar support and test equipment procurement costs.

5. Site Preparation

The area of site preparation costs is not an easy area to provide estimations for new system installations. In the authors opinion the best method to determine the costs in this category is through one of three methods; 1) have contractor(s) provide the site preparation and

construction cost information with the initial bid, 2) through consultation with Coast Guard civil and electrical engineers, using estimates from similar type projects, 3) a combination of both of the above methods. Normally, both the contractor and the Coast Guard engineers should have a fairly reasonable idea of what these costs will be given the requirements set out in your system specification. An additional source of site preparation cost information, if none of the above methods work out, is the use of a planning factors manual such as DCA Circular 600-60-1.

6. Coast Guard/Government Peculiar System Design and Engineering Requirements

There seems to be only one source for system design and engineering costs required to enable an "off the shelf" system to meet peculiar Coast Guard or Government standards, and that would be the contractors/manufacturers (which here after will be referred to as contractors) bid for the new system(s). Therefore you would have to rely on the contractor to provide information concerning this cost category.

7. Initial Technical Data and Documentation Procurement

In order to determine the technical data/documentation costs for the initial procurement of a system, there are several ways to obtain this information. The first method is for the information to be provided by the contractor in the initial bid. The contractor would

certainly include this as a cost on the bid, which would vary based on how much of the technical data on the system the Coast Guard requires, and on how much the contractor is willing to let the Coast Guard have access to.

A second method to determine these costs is through a cost per page multiplied by the number of pages required by the Coast Guard. This could be used if a estimate/value for cost per page could be determined.

8. Transportation Costs

In the procurement of new systems, the Coast Guard pays the transportation cost for the system from the contractor to the point of installation, The contractor may provide the cost for equipment transportation, and make the arrangements for the equipment delivery. In other cases it may be left to the government to arrange for transportation via its own shipping sources. To determine the transportation cost the following equation can be used:

$$\text{Transportation Costs} = 2 \times (\text{Unit Weight}) \times (\text{distance}) \times (\text{Cost per lb/mile})$$

If the cost per lb/mile is not readily available, it is recommended to use \$.001 for short distances (less than 50 miles), and \$.00013 for long distances.[Ref. 5: p. C-14]

B. OPERATION AND MAINTENANCE (O&M) COSTS.

The operations and maintenance (O&M) costs will normally be applicable to both the presently installed and proposed

telecommunications systems. Therefore the costs that are outlined below will be applied to both system.

1. Operating and Maintenance Personnel Costs

The first category under O&M costs that will be examined is the costs of operating and maintenance personnel.

a. Operator Personnel Costs

Normally, in the Coast Guard there are very few, if any operating personnel for telephone system(i.e. operators, switchboard operators), except with the possible exception of programmers of PBX's, which may well be considered as part of maintenance or system administration personnel.

If there are operators for Coast Guard telephone/data systems, the following equations are appropriate:

$$\text{Operator Personnel Cost} = \left|\begin{array}{c}\text{Nr. of}\\ \text{Man-Hours}\\ \text{per}\\ \text{Operating}\\ \text{Hour}\end{array}\right| \times \left|\begin{array}{c}\text{Cost of}\\ \text{Operator}\\ \text{Personnel}\end{array}\right| \times \left|\begin{array}{c}\text{Number of}\\ \text{Operating}\\ \text{Hours per}\\ \text{Year}\end{array}\right| \times \left|\begin{array}{c}\text{Quantity of}\\ \text{Operational}\\ \text{Equipment}\end{array}\right|$$

Where the units for the variables are as follows:

Number of man-hours per operating hour = MH/Op.Hr.

Cost of operator personnel = $/Hr.

Number of operating hours per year = Hr/Yr.

Quantity of operational equipment = units

[Ref. 5: p. C-3]

The cost of operator personnel will be discussed in more detail later, particularly concerning military personnel costs.

An alternate equation to determine operator personnel costs is as follows:

$$\text{Operator Personnel Costs} = \left|\begin{array}{l}\text{Annual Pay and}\\\text{Allowances of}\\\text{Operators}\end{array}\right| \times \left|\begin{array}{l}\text{Nr. of}\\\text{Operators}\\\text{Required}\\\text{per Equip.}\end{array}\right| \times \left|\begin{array}{l}\text{Quantity of}\\\text{Operational}\\\text{Equipment}\end{array}\right|$$

Where

Annual pay and allowances of operators has units of $/Yr/person.[Ref. 5: p. C-3]

This equation assumes that a person is fully dedicated to the operation of a telecommunications system, which many times may well not be the case.

b. Maintenance Personnel Costs

As was discussed earlier in this chapter, the costs that are incurred for the actions of maintenance personnel in the carrying out of their duties is dependent on the level of repair that have been established for the telecommunications systems that are being examined. The level of repair policy for the presently installed system has long been established and should be easily determined. On the other hand, the level of repair policy for the proposed system will most likely be established by the Coast Guard's specification, and the contractors design in order to meet the requirements for MTBF (mean time between failure), M_{ct} (mean corrective maintenance time), and MTBM

(mean time between maintenance), which includes the times required for preventive maintenance. With more reliance on integrated circuitry, preventive maintenance for telephone/data systems should be reduced, if not eliminated.

The overall cost for maintenance personnel as related to a telecommunications system can be described by the following formula:

$$\begin{array}{l} \text{Maintenance} \\ \text{Personnel} \\ \text{Cost} \end{array} = \left|\begin{array}{l} \text{Organizational} \\ \text{Maintenance} \\ \text{Personnel} \\ \text{Cost} \end{array}\right| + \left|\begin{array}{l} \text{Intermediate} \\ \text{Maintenance} \\ \text{Personnel} \\ \text{Cost} \end{array}\right| + \left|\begin{array}{l} \text{Depot} \\ \text{Maintenance} \\ \text{Personnel} \\ \text{Cost} \end{array}\right|$$

[Ref. 5: p. C-4]

All these variables have units of \$/Yr, and each maintenance personnel category will be expanded below.

(1) <u>Organizational Maintenance Personnel</u>. Organizational maintenance personnel costs can be described by the following:

$$\begin{array}{l} \text{Organizational} \\ \text{Maintenance} \\ \text{Cost} \end{array} = \left|\begin{array}{l} \text{Preventive} \\ \text{Maint.} \\ \text{Time} \end{array}\right| + \left|\begin{array}{l} \text{Corrective} \\ \text{Maint.} \\ \text{Time} \end{array}\right| \times \left|\begin{array}{l} \text{Cost of} \\ \text{Organ.} \\ \text{Maint.} \\ \text{Person-} \\ \text{nel per} \\ \text{Hour} \end{array}\right| \times \left|\begin{array}{l} \text{Quantity} \\ \text{of Oper.} \\ \text{Equip.} \end{array}\right|$$

Where:

$$\begin{array}{l} \text{Corrective} \\ \text{Maintenance} \\ \text{Time} \end{array} = \begin{array}{l} \text{Nr. of} \\ \text{Operational} \\ \text{Hrs per Yr} \end{array} \times \left|\frac{M_{ct}}{MTBF}\right|$$

[Ref. 5: p. C-4]

Preventive maintenance times would normally be determined from contractors specifications for such, or from practices that are developed by the Coast Guard (i.e. owner

agency). If the preventive maintenance is developed by the owners of the equipment/system it would be due to a need that the owner perceives to obtain longer operating hours between unscheduled maintenance, and possibly to provide training for maintenance personnel. The actual preventive maintenance time is dependent on 1) how often preventive maintenance is performed, i.e. every 6 months, every 4000 operating hours etc., and 2) the time required to carry out the preventive maintenance. Therefore, if preventive maintenance is carried out every 6 months, and requires two hours, preventive maintenance time for the system would be 4 hours per year.

An alternate formula for organizational maintenance personnel cost is outlined below:

$$\begin{array}{l} \text{Organizational} \\ \text{Maintenance} \\ \text{Personnel} \\ \text{Cost} \end{array} = \left| \begin{array}{l} \text{Annual Pay} \\ \text{and Allow-} \\ \text{ances of} \\ \text{Organ.} \\ \text{Maint.} \\ \text{Personnel} \end{array} \right| \times \left| \begin{array}{l} \text{NR. of Organ.} \\ \text{Maint. Person.} \\ \text{per equip.} \end{array} \right| \times \left| \begin{array}{l} \text{Quantity of} \\ \text{Organ. Equip.} \end{array} \right|$$

[Ref. 5: p. C-5]

The above formula makes the assumption that one maintenance personnel or all the personnel working on a piece of equipment or system sums to at least one man-year. In some cases this may be a very reasonable equation to use, but the author tends to favor the prior equation for organizational maintenance personnel costs, as the estimated times required for maintenance are used versus requiring the estimation of

the number of maintenance personnel that all persons maintaining the system would equate to if personnel were dedicated to the system.

(2) Intermediate Maintenance Personnel Costs. Intermediate maintenance personnel costs such as incurred at ESMT's, ESM's and any other local government electronics shop can be developed by the following:

$$\text{Intermediate Maintenance Personnel} = \left| \frac{\text{OPHR} \times \text{QTY}}{\text{MTBF}} \right| \times \%\text{I} \times \text{MTR} \times \$\text{I}$$

Where;

OPHR = Operating Hours per Year.

QTY = Quantity of Operational Equipment.

MTBF = Mean Times Between Failures (in Hours).

%I = % of All Failed Modules to be Repaired/Discarded at Intermediate Level.

MTR = Module Mean Time to Repair.

$I = Cost of Intermediate Personnel per Hour.

[Ref. 5: p. C-6]

The above equation is geared toward a piece of equipment or system, and "% of all failed modules to be repaired/discarded at the intermediate level" refers to the abilities/capabilities of the electronics shop to either repair a piece of equipment/module or determine that it is not repairable and discard. Module mean time to repair (MTTR) refers to the average time to repair all modules and pieces of equipment. An alternate equation is listed below:

$$\text{Intermediate Maintenance Cost} = \left[\begin{array}{l}\text{Annual Pay and}\\\text{Allowance of}\\\text{Intermediate}\\\text{Maintenance}\\\text{Personnel}\end{array}\right] \times \left[\begin{array}{l}\text{Nr. of}\\\text{Intermediate}\\\text{Maintenance}\\\text{Personnel per}\\\text{Equipment}\end{array}\right] \times \left[\begin{array}{l}\text{Quantity of}\\\text{Operational}\\\text{Equipments}\end{array}\right]$$

[Ref. 5: p. C-6]

As mentioned earlier this type of equation assumes that at least one man-year of maintenance personnel time is involved in any one piece of equipment or system. The above equation, "however accounts for the total pay and allowances of intermediate maintenance personnel and is suitable for budget estimates, base line cost estimates and independent parametric cost estimates where equipment parameters of MTBF, MTTR, are not considered in estimating personnel costs" [Ref. 5: C-6]. An additional point is that the number of intermediate maintenance personnel per equipment value could be considered personnel required per intermediate maintenance site/facility, and the quantity of operational equipment value could be the quantity of intermediate maintenance sites/facilities.[Ref. 5: p. C-6]

(3) Depot Maintenance Personnel. As in the other maintenance personnel cost categories, depot maintenance personnel costs can be described by two equations:

$$\text{Depot Maintenance Personnel Cost} = \left[\begin{array}{l}\text{Annual Cost}\\\text{of Depot}\\\text{Maintenance}\\\text{Personnel}\end{array}\right] \times \left[\begin{array}{l}\text{Nr. of Depot}\\\text{Depot Maintenance}\\\text{Personnel}\end{array}\right]$$

or by

$$\text{Depot Maintenance Personnel} = \left| \frac{\text{OPHR} \times \text{QTY}}{\text{MTBF}} \right| \times \%D \times \text{MTR} \times \$D$$

Where;

OPHR = Operating Hours per Year.

QTY = Quantity of Operational Equipment.

MTBF = Mean Time Between Failure.

%D = % of All Failed Modules to be Repaired/Discarded at the Depot Level.

MTR = Module Mean Time to Repair.

$D = Cost of Depot Maintenance Personnel per Hour.

[Ref. 5: p. C-7]

The author prefers the second equation as it would seem to be more accurate, unless the depot was dedicated to the repair of a system and only to the Coast Guard's needs, which in all likelihood is not the case.

The Coast Guard in most cases has few depot level repair facilities, particularly dedicated to telecommunications systems, so these repairs are normally carried out by the manufacturer or a third party company. The contract maintenance costs would be specified in the contract, such as a basic retainer, plus costs for parts and labor above a specified level. Therefore, these equations may not have to be used, as the contract bid would provide all the above information.

(4) Contract Maintenance Personnel. All the maintenance personnel categories, make the assumption that military or government civilian employees would be doing equipment/system maintenance. This may well not be the case for telecommunications systems, with the Coast Guard's implementation of the requirements set forth by OMB Circular A-76, and the fact that in the opinions of Coast Guard financial and personnel specialist, shore side telecommunications systems and most electronics shops are good areas to contract out to civilian firms and fitting with the goals of OMB Circular A-76. Therefore, much of maintenance personnel costs that fit within the scope of this thesis may well be covered by contract specifications and the costs can be determined from these contracts.

2. Energy Consumption Costs

As any telecommunications system requires some power source to operate, normally electrical. Then the energy consumption costs can be determined by the following equation:

$$\text{Energy Consumption Cost} = \left|\begin{array}{l}\text{Average}\\ \text{Electrical}\\ \text{Power}\\ \text{Rating}\end{array}\right| \times \left|\begin{array}{l}\text{Cost of}\\ \text{Elec-}\\ \text{trical}\\ \text{Power}\end{array}\right| \times \left|\begin{array}{l}\text{Nr. of}\\ \text{Operating}\\ \text{Hrs per}\\ \text{Yr}\end{array}\right| \times \left|\begin{array}{c}\text{Quantity of}\\ \text{Operational}\\ \text{Equipment}\end{array}\right|$$

Where the units of the variables are as follows:

Average electrical power rating = Kilowatts

Costs of electrical power = $/Kilowatt-Hr

Number of operating hours per year = Hours/Year

[Ref. 5: p. C-2]

This equation makes the assumption that power is being purchased from a public utility, or a government organization that charges on a similar price structure. If the Coast Guard was producing its own power from diesel generators it would then have to determine the cost per Kilowatt-Hour of fuel to operate the generators, a possible estimate such as $0.04 per Kilowatt-Hour, which was a 1978 estimate and slightly exceeded commercial electricity costs at the time. [Ref. 5: p. C-2]

3. Material Consumption Costs

Material consumption costs (such as paper, ribbons, etc.) should not be a major cost for a telecommunications system, such as telephone or data system. The costs however will be incurred for any system monitoring equipment, and administrative overhead involving paper work. Therefore, this cost category can be determined by the following equation:

$$\text{Material Consumption Cost} = \left|\begin{array}{l}\text{Material}\\\text{Consumption}\\\text{Rate}\end{array}\right| \times \left|\begin{array}{l}\text{Cost of}\\\text{Consumable}\\\text{Materials}\end{array}\right| \times \left|\begin{array}{l}\text{Quantity of}\\\text{Operational}\\\text{Equipment}\end{array}\right|$$

Where the variables have the following units:

Material consumption rate per unit	=	variable (e.g. Pages/Yr, Rolls/Yr, etc.)
Cost of consumable materials	=	\$/page, \$/roll, etc.

[Ref. 5: p. C-2]

4. Administrative And Supply Personnel Costs

Administrative and supply personnel are usually involved in 1) overseeing and directing the operation of a system/piece of equipment, 2) providing and insuring that consumable materials, spares, and replacement parts are provided, or 3) insuring that budgeting concerns are handled. Normally no one system takes, or requires the full attention of these personnel, but only a fraction of their working hours. It is therefore necessary to determine the portion of personnel time (both administrative and supply personnel) that is taken up or will be taken up by involvement in the administration of the presently installed system or the proposed system.

a. Supply Personnel

The supply personnel costs can be determined by the following equations:

$$\text{Supply Personnel Cost} = \left|\text{Organizational Supply Personnel Cost}\right| + \left|\text{Intermediate Supply Personnel Cost}\right| + \left|\text{Depot Supply Personnel Cost}\right|$$

[Ref. 5: p. C-8]

Where the variables are determined by the following equations:

Organizational Supply Personnel Cost	=	0.03	x	Organizational Maintenance Personnel Cost

[Ref. 5: p. C-9]

And

Intermediate Supply Personnel Cost	=	0.03	x	Intermediate Maintenance Personnel Cost

[Ref. 5: p. C-9]

And

Depot Supply Personnel Cost	=	0.03	x	Annual Cost of Depot Maintenance Personnel	x	Nr. of Depot Maintenance Personnel

[Ref. 5: p. C-7]

The above equations make the assumption that 3% of maintenance personnel costs equates to the supply personnel costs to properly support the system/equipment.

An alternate means to determine the supply personnel costs is to assume that the number of supply personnel between an old system and proposed system will remain constant, or the variation will be determinable. The next step is to determine the portion of each persons time that is dedicated to the system/equipment that is being examined. The supply personnel costs can then be determined by the following equation:

$$\text{Supply Personnel Costs} = \sum_{\substack{\text{all} \\ \text{supply} \\ \text{personnel}}} \left| \begin{array}{l}\text{\% of Personnel} \\ \text{Time Dedicated} \\ \text{to System}\end{array} \times \begin{array}{l}\text{Annual Pay and} \\ \text{Allowances of} \\ \text{Supply Personnel}\end{array} \right|$$

b. Administrative Personnel

Administrative personnel costs can be determined as described above by the following:

$$\text{Administrative Personnel Costs} = \sum_{\substack{\text{all} \\ \text{admin} \\ \text{personnel}}} \left| \begin{array}{l}\text{\% of Personnel} \\ \text{Time Dedicated} \\ \text{to System}\end{array} \times \begin{array}{l}\text{Annual Pay and} \\ \text{Allowances of} \\ \text{Administrative} \\ \text{Personnel}\end{array} \right|$$

5. <u>Replenishment Spares And Repair Material Costs</u>

To determine the replenishment spares and repair material costs there are several ways to make these determinations. One manner is outlined below:

$$\begin{array}{l}\text{Replenishment} \\ \text{Spare and} \\ \text{Repair} \\ \text{Material} \\ \text{Costs}\end{array} = \left| \begin{array}{l}\text{Inventory} \\ \text{Replenishment} \\ \text{Cost Factor}\end{array} \right| \times \left| \begin{array}{l}\text{Equipment} \\ \text{Unit} \\ \text{Procure-} \\ \text{ment Cost}\end{array} \right| \times \left| \begin{array}{l}\text{Quantity of} \\ \text{Operational} \\ \text{Equipment}\end{array} \right|$$

[Ref. 5: p. C-9]

Where the inventory replenishment cost factor refers to the turnover rate of spares and repair materials that are held on inventory, with units of percent/yr. This factor is related to the MTBF of a piece of equipment or module, and the desired probability that when needed a part will be available. The values for this variable may be 5% [Ref. 5: p. C-9] or 7% [Ref. 4: p. 22-2] depending on the source document referred to.

When examining the presently installed system you should be able to establish what the annual cost for spares has been, and quite possibly determine a relationship to MTBF. Additional determinations may require more spares, if operating components of the system are geographically dispursed.

An Alternate method of determining replenishment spares and repair material costs is outlined by the following set of equations:

$$\text{Spare and Repair Material} = \text{Organizational Maintenance Spares Cost} + \text{Intermediate/Depot Maintenance Spares Cost} + \text{Repair Material Cost}$$

Where;

$$\text{Organizational Maintenance Spare Cost} = \frac{\text{OPHR} \times \text{QTY} \times \text{\$DISCARD}}{\text{DMTBF}}$$

Where;

OPHR = Operating Hours per Year.

QTY = Quantity of Operational Equipment.

\$DISCARD = Average Cost of Discarded Modules.

DMTBF = Mean Time Between Failure of Discarded Modules.

And

$$\text{Intermediate/Depot Maintenance Spare Costs} = \frac{\text{OPHR} \times \text{QTY} \times \text{\$REPAIR} \times \text{DR}}{\text{RMTBF}}$$

Where;

OPHR = Operating Hours per Year.

QTY = Quantity of Operational Equipment.

\$REPAIR = Average Cost of Repair Modules.

DR = Discard Rate.

RMTBF = Mean Time Between Failures of Repairable Modules.

And

$$\text{Repair Material Cost} = RMR \times \left| \frac{OPHR \times QTY \times \$REPAIR \times (1 - DR)}{RMTBF} \right|$$

Where;

RMR = Repair Material Rate.

OPHR = Operating Hours per Year.

QTY = Quantity of Operational Equipment.

\$REPAIR = Average Cost of Repair Modules.

DR = Discard Rate.

RMTBF = Mean Time Between Failure of Repairable Modules.

[Ref. 5: p. C-10]

The above group of equations assumes that repairs at the organizational level are mostly module replacement and fixed wiring repairs, which for the present and future telecommunications systems seem to be a good assumption. These equations also require a prior determination of the level of repair for different major components of the system. This may not always be possible, as these details

may not be available for a proposed system. If however, this kind of analysis can be done it should insure the most efficient and cost effective maintenance policy. The discard rate refers to the percentage of modules that repair will not be attempted upon failure, as it is determined not to be cost effective. The repair material rate refers to the percentage of the average cost of repair modules that is required to be expended in order to repair these modules. The remainder of the variables in the equation are self explanatory.

6. Inventory Administration Costs

Inventory Administrative costs involve the cost of inventory management, inventory holding, and technical data support. Inventory administration costs can be described by the following equations:

$$\begin{array}{l}\text{Inventory}\\ \text{Administration}\\ \text{Costs}\end{array} = \left|\begin{array}{l}\text{Inventory}\\ \text{Management}\\ \text{Cost}\end{array}\right| + \left|\begin{array}{l}\text{Inventory}\\ \text{Holding}\\ \text{Costs}\end{array}\right| + \left|\begin{array}{l}\text{Technical Data}\\ \text{Support Costs}\end{array}\right|$$

Where;

$$\begin{array}{l}\text{Inventory}\\ \text{Management}\\ \text{Cost}\end{array} = \text{FSN} \times \left|\frac{\text{YRC} + (\text{ARC} \times (\text{YLC} - 1))}{\text{YLC}}\right|$$

Where;

FSN = Number of New Federal Stock Number (FSN) Items.

1YRC = 1ST Year Recurring Cost.

ARC = Annual Recurring Cost.

YLC = Number of Years per Life Cycle.

[Ref. 5: p. C-11]

This equation relies on Table I (which is based on 1978 estimates and may well be out of date):

Table I. Inventory Line Item Management Costs

FSN Dollar Value	Introduction Costs	First Year Recurring Cost	Annual Recurring Costs
Over - $500,000	$306	$1,439	$1,439
$50,000 - $500,000	306	918	918
$ 5,000 - $ 49,999	306	326	326
Under - $ 5,000	306	236	236

[Ref. 5: p. C-11]

The above equations variables refers to number of new FSN Items, where FSN is an abbreviation for federal stock number, which means that the items for the new system, which are not already within the federal stock system must be added. Many times the Coast Guard procures systems, and relies directly on the manufacturer for the spares for its inventory, therefore the costs in the above table may be much higher that the Coast Guard's actual inventory

management costs, even if the Coast Guard provides an inventory on a service wide basis.

The inventory distribution/holding costs can be described by the following equation:

$$\text{Inventory Holding Cost} = \begin{bmatrix} \text{Inventory} \\ \text{Distribution} \\ \text{/Holding} \\ \text{Cost} \\ \text{Factor} \end{bmatrix} \times \begin{bmatrix} \text{Average \$ Value} \\ \text{of Total Spares} \\ \text{in Storage over} \\ \text{the Life Cycle} \end{bmatrix}$$

[Ref. 5: p. C-12]

Inventory holding is the cost of holding inventory in the supply system for one year, which involves the measurement of storage costs, and other losses. The Inventory Distribution/holding cost factor is recommended to be at 3%, which is made up of the following factors:

Other Losses	2%
Storage Costs	1%
Total	3%

Where the other losses refer to the opportunity costs of not using the funds that are tied up in inventory elsewhere. The average dollar value of total spares in storage includes the average value of both the initial spares purchased during the acquisition contract and the replenishment of spares used during the life cycle.[Ref. 5: p. C-12]

The technical data support costs are the costs of keeping all technical data on the system/equipment up to date to insure the smooth operation and maintenance of the system/equipment. This may be impossible to determine, but is described by the following equation:

$$\text{Technical Data Support Cost} = \begin{bmatrix}\text{Technical} \\ \text{Data Pages} \\ \text{Requiring} \\ \text{Revision}\end{bmatrix} \times \begin{bmatrix}\text{Technical} \\ \text{Data Management} \\ \text{Costs}\end{bmatrix}$$

[Ref. 5: p. C-13]

The technical data pages requiring revision is a measure of how much the system/equipment is modified from year to year. The technical data management costs are affected by numerous factors such as the number of engineers involved in the designing of the changes to the system, and the number of persons involved in the making of the necessary changes to the technical manuals.

7. Transportation Costs

For the determination of these costs refer to acquisition and installation section, where they are described sufficiently.

8. Personnel Training/Retraining Costs

As discussed under initial maintenance and administrative personnel training in the acquisition and installation section of this chapter, much of the personnel training costs will have to be determined from the amount that will be charged by the manufacturer or third party company to train Coast Guard personnel (both civilian and military). Added to the costs charged for training are the travel and per diem costs for Coast Guard personnel to travel and stay at the training facility or for the trainer to travel to the Coast Guard facility. During the

operations and maintenance (O&M) of a system's equipment life cycle, the personnel training costs are affected by how often training of new personnel or training of established personnel will be required.

To determine how often new personnel training is required there are at least two methods. The first method is to make an estimate of how often and how many trained personnel will rotate for a given period, perhaps a year. This will provide a rough estimate of the number of personnel that will require training during a year for a particular system or a group of equipments. This method does have it weaknesses, being that even if new personnel are assigned, that does not necessarily mean that training will be required, particularly if the system is used service wide. The second method is to determine the training requirement by the use of the replacement turnover rate (RTR), which is described by the following equation:

$$RTR = \frac{\text{Yearly Enlisted Classification (EC) Training Requirem't}}{\text{Total Billet Required By EC}}$$

[Ref. 5: p. D-21]

Where enlisted classifications refer to rates, and in some case would refer to specific qualification codes for particular equipment.

> Since training, and to a lesser extent billet requirements fluctuate, a leveling out of these requirement can be accomplished by using an average of 6 years for EC billet requirements and an average of 5 years for EC training requirements[Ref. 5: p. D-21].

Therefore

$$\text{RTR}=\frac{\dfrac{\text{EC Training Requirements}}{5}}{\dfrac{\text{EC Billet Requirements}}{6}}$$

[Ref. 5: p. D-21]

The RTR is then used by multiplying it by the number of a specifically trained personnel that are assigned, to determined the number of personnel that will have to be retrained each year. In the authors opinion the RTR should be equal to 1-(retention rate), for enlisted ratings with specific qualification codes within the Coast Guard. Then the yearly training costs would again be determine by the number of personnel requiring training multiplied by the cost of this training.

9. Maintenance Facilities Costs

Maintenance facilities costs will normally be absorbed into part of the overhead costs of the organization, particularly if all maintenance facilities maintain multiple and diversified systems and equipments. If on the other hand a maintenance facility is dedicated to the maintenance of a particular system/equipment group. Then these cost should be included in the life cycle costs (LCC) of the system. In order to determine the above, the yearly costs for electricity, building maintenance and up keep must be figured. In the Coast Guard a dedicated repair

facility for a particular system is a rarity, therefore this topic will not be pursued further.

10. Support Equipment Maintenance Costs

Support equipment maintenance costs are those normally related to equipment/systems that are used to aid in the operation and maintenance of a system or group of equipments, including test and repair equipment. One method to determine these costs is through the use of the following equation:

$$\text{Support Equipment Maintenance Cost} = \begin{bmatrix}\text{Support} \\ \text{Equipment} \\ \text{Maint.} \\ \text{Factor}\end{bmatrix} \times \begin{bmatrix}\text{Cost of Common and} \\ \text{Peculiar Support} \\ \text{Equipment}\end{bmatrix}$$

[Ref. 5: p. C-8]

Where the support equipment maintenance factor is normally assumed to be 10%. This cost equation determines the support equipment maintenance cost for the entire life cycle of the equipment.

An alternate method to determine the support equipment maintenance costs is if the support equipment required for the system has been determined in the acquisition and installation phase, you can then treat the support equipment in the same manner as the basic equipment. The determination of the maintenance costs would then be a summation of the material consumption, replenishment spares and repair material, transportation , and personnel costs using the equations described earlier.

C. ANNUAL PAY AND ALLOWANCES OF MILITARY/CIVILIAN PERSONNEL

Throughout this chapter many references have been made to annual pay and allowances of personnel, whether they be maintenance, operation, or support personnel (military or civilian). Therefore, it is important to discuss in general terms what items would be accounted for in the determination of the proper value for annual pay and allowances. The first item that must be examined is for what pay level are you drawing this annual pay and allowances. The normal manner to determine the proper pay level required to fill a designated job is through analysis of the technical, management, and experience level required to do the job. The next step is to take the developed job specification and thoroughly examine the Coast Guard Staffing Standards Manual (COMDTINST M5312.11), and, if civilian employment is being considered, the input of the civilian personnel job categorizing specialist. Then determine the rank/rate or GS/WG level that will be required to fill the position. This process is repeated for all positions that are required for an individual system. Since this thesis is looking at maintaining a present or installing a new system, there may not be personnel changes required, this may be particularly true if personnel position's are not fully justified by a particular system.

When an equation in this chapter refers to annual pay and allowances of personnel it is referring to the average pay and allowance of all the personnel that effect the cost that is being described. Then the best way of determining the desired value for annual pay and allowances is to determine the total personnel cost for the area of concern (i.e. maintenance, supply, etc.), that can be directly related to a system/equipment group, and then dividing by the number of directly related personnel.

When determining the annual pay and allowances for personnel involved in a system it is important to understand what makes up the pay and allowance of these personnel. The first component is the basic pay which "represents a weighted average for longevity", which increments for each pay grade[Ref. 5: p. D-5]. Allowances include those items that effect the military persons pay, but are normally not taxed. The allowances include the following:

a. Sea duty pay or other special pay.

b. Basic allowance for quarters (BAQ)-provided unless government housing or government leased housing is provided.

c. Subsistence allowance-for food-format differs between officers and enlisted.

d. Variable housing allowance (VHA)-adjusts BAQ for housing costs for each geographic area.

e. Cost of living allowance (COLA)-provided to service members residing in high cost areas, normally overseas, alaska and hawaii.

Government civilian employees, normally fall in to two categories: general service (GS), or wage grade (WG). The GS employees are paid a base pay dependent on their grade level, and if authorized overtime may be paid. Additionally, in certain areas GS employees receive COLA. WG employees on the other hand are paid an hourly rate, with no base pay level.

D. CIVILIANIZATION

With the initiatives brought about by OMB circular A-76, and the Coast Guard's acceptance that it will have to comply with these regulations, many functions that in the past and are presently carried out by military personnel or government employees will be contracted out to firms on a long term basis. In some cases the long term operation and maintenance contracts may be part of the installation package for a system, or may be separate and system independent, i.e. one firm having the contract for all electronics maintenance and repair within one Coast Guard district. The recent trend indicates that telecommunications and electronics systems are one area where contracting to private firms will be done. Therefore many of the equations and relationships discussed in this chapter may not need be used. What will be necessary is to refer to the contracts to see what the costs are, and what changes in these costs will occur if a new system is placed in operation.

The next step in the examination of this methodology, having looked at the system cost factors, is the examination of the non-cost factors (i.e. performance/capability measures) that are important to the development of this methodology.

IV. NON-COST FACTORS

In this chapter non-cost factors will be examined. The factors that will be looked at are factors related to performance and capability. There are many such factors, some easy to measure and some very difficult to measure. The author will limit the factors examined to those that he feels are most important to the decision maker. The factors that will be examined:

a. Number of communication channels.

b. System reliability.

c. Man-hours in overhead.

d. Savings in user man-hours.

e. Bandwidth.

f. Ease of reconfiguration.

Again, these are not all the possible factors that may be important, but they are felt to provide a good basis for judgments. Detailed descriptions and possible measurement methodology for each of these factors follow.

A. NUMBER OF COMMUNICATIONS CHANNELS

This factor is intended as a measure of the capacity of the system. The measure is the number of communications paths (circuits) that are provided and available for use. The paths are, for example, the number of internal

extensions and outside lines a PBX has in operation and available for future expansion. The number of communication channels that a microwave system provides between two geographic points is also an example of the paths.

This measure is determined through examination of the operations and engineering specifications for the systems, and therefore represents the maximum communications capacity of the systems.

B. SYSTEM RELIABILITY

"Reliability can be defined simply as the probability that a system or product will perform in a satisfactory manner for a given period of time when used under specified operation conditions".[Ref. 1: p. 12] The definition of reliability stresses probability, satisfactory performance, time, and specified operating conditions. Probability is the percentage of successes that occur during a testing cycle which, with reasonable certainty, will be replicated during actual operations. Satisfactory performance refers to the system operating within specific criteria which have been established for the operation of the system. These specific criteria, referred to as operating and engineering specifications are a combination of qualitative and quantitative factors that define what the system is to accomplish.

Time is considered the most important element of reliability and of particular interest is the ability to predict the probability of an item surviving (without failure) for a designated period of time. Reliability is frequently defined in terms of mean time between failure (MTBF), mean time to failure (MTTF), or mean time between maintenance (MTBM).

The specific operating conditions refer to the conditions the system is expected to operate under. "These conditions include environmental factors, such as geographical location, operational profile, transportation profile, temperature cycles, humidity, vibration, shock, and so on. Such factors must not only address the conditions for the period when the system or product is operating, but the conditions for the periods when the system is in storage or being transported from one location to the next. Experience has indicated that the transportation, handling, and storage of equipment is sometimes more critical from the reliability standpoint, than the conditions experienced during actual system operational use".[Ref. 1: p. 13]

Reliability can be described by the following relationship:

$$R(t) = e^{-t/m} = e^{-\lambda t}$$

Where

$R(t)$ = Reliability as a function of time.
t = Time
m = MTBF
λ = Failure rate = $\dfrac{\text{Number of failures}}{\text{Total Operation Hours}}$

Further

$= 1/\theta = 1/\text{MTBF}$ or $\text{MTBF} = 1/\lambda$

[Ref. 1: pp. 24-26]

Where

θ = Mean life of product/equipment.

The exponential relationship of the reliability function can be illustrated in Figure 4.1, as a function of reliability and normalized time:

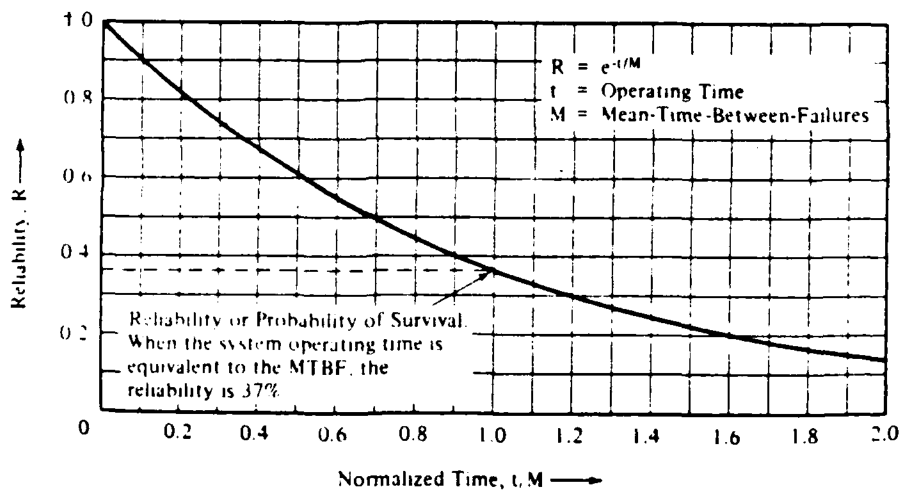


Figure 4.1. Reliability Versus Normalized Time

[Ref. 1: p. 25]

From the above discussion it should be clear that reliability and mean time between failure (MTBF) are directly related, such that the longer the MTBF, the greater

the reliability of the system for a longer operating cycle. Therefore, for a measure of the reliability of the systems that are examined, mean time between failures (MTBF) will be used. If it is determined that preventive maintenance is to be carried out on a system, mean time between maintenance (MTBM) will be used, versus mean time between failure (MTBF). This is due to the fact that during the preventive maintenance actions the system is not operational, and therefore not available for use.

In order to determine these values, different methodology will be used for the presently installed system than for the proposed new system. For the presently installed system the actually experienced MTBF (MTBM) should be determined. For the proposed new system manufacturers estimates of the MTBF (MTBM) should be employed.

C. MAN-HOURS IN OVERHEAD

The overhead of the systems refers to all administrative, supply, and maintenance personnel that are involved in the system's operation in a direct manner. A direct manner is defined as any personnel who either work directly on the equipment or provide supply or administrative support to the systems, such as ordering materials, paying accounts receivable, or preparing required reports that are related to the systems. Normally in the Coast Guard most personnel are not dedicated full-time to a

system. Therefore, it is necessary to determine how much of their work time over the year is dedicated to the presently installed system, or would be dedicated to the proposed replacement system.

In order to determine the man-hours dedicated to the particular systems the following procedures is viable: For administrative and supply personnel, the best method to determine the man-hours that they are directly involved in support of the systems is to determine what percentage of their working hours for a specified period is involved with supporting the system. This can be done for the presently installed system by surveying the personnel that have been identified to be in this category, or by having them keep track of the time they did work related to the system. For the proposed system a scientific estimation would have to be carried out by examining the times that are dedicated to the present system, and looking at differences in supply ordering (different MTBF's), reports, and other requirement for the new systems. An example of this might be that there is presently a supply clerk who dedicates 40% of his/her time sorting, administering and verifying phone bills for a district office. The proposal is to replace the presently installed private branch exchange (PBX). The new PBX has a billing program that establishes what office, extension, cost per phone call, and then sorts by extension group (i.e. by office). It is likely that this feature will cut the

time required by the supply clerk dedicated to the above task. It is then necessary to determine how much time will no longer be required to be dedicated to the billing verification process, let it be in this case a 20% reduction. Then with the new system only 20% of the clerks man-hours will be dedicated to the system. Something that must be made clear is that the reduced man-hours are not saved, but no longer dedicated to supporting the telecommunications systems.

It is now left to determine the man-hours of system overhead that are involved in maintenance. To determine the man-hours that have been dedicated to the presently installed system can be done by two methods. The first is though the actual hours organizational or contract personnel have worked on the system/equipment, if this data is available from records or personnel surveys. The second method, which would also be used for the proposed system is to determine via the use of the MTBF (or MTBM), total operating hours of the equipment, and the mean corrective maintenance time (M_{ct}), or Mean active maintenance time (M), if preventive maintenance is carried out. The first step is to determine the number of maintenance actions per year by the following equation:

$$\text{Maintenance Actions} = \frac{\text{Total Operating Hrs for equip/yr}}{\text{MTBF}}$$

[Ref. 1: p. 99]

Where Maintenance Actions has units of actions/year. If preventive maintenance is carried out, MTBM will be substituted for MTBF.

The next step is to determine the hours per year in maintenance by the following equations:

Man-hours in Maintenance = M_{ct} x number of maintenance actions

or

Man-hours in Maintenance = M x number of maintenance actions

where

$$M = \frac{(\lambda)(M_{ct}) + (f_{pt})(M_{pt})}{\lambda + f_{pt}}$$

[Ref. 1: p. 43]

λ = Failure rate.

f_{pt} = *Frequency of preventive maintenance.*

M_{pt} = Mean preventive maintenance time.

Therefore

Man-hours in maintenance(with preventive maintenance)

$$= (\lambda)(M_{ct}) + (f_{pt})(M_{pt})$$

This maintenance man-hours calculation must be carried out for all repair levels with the Coast Guard involved in a systems maintenance. Once the administrative, supply, and maintenance hours are determined. It is then necessary to sum these hours, in order to obtain the total man-hours in overhead.

D. SAVINGS IN USER MAN-HOURS

If after examination of the operational and engineering specifications of the proposed system. It looks as if the proposed system will reduce the organizational personnel man-hours related to the use of a telecommunications system, as compared to the hours required by the present system, this category should be developed. An example that would merit such a development would be the move from a rotary telephone system to a touch tone (DTMF) telephone system. Since it would require less time to dial via touch tone than with a rotary telephone.

To develop this factor would require documentation of organizational personnel time involved in the operation and/or use of the present system and an estimation of their involvement time with the proposed system.

E. BANDWIDTH

Bandwidth is directly related to the speed of transmission for digital signals (whether voice or data), the wider the bandwidth the faster are the transmission speeds. The values for the bandwidth of the installed and proposed systems can be obtained from the two system engineering specifications. If the useable bandwidth is increased this means increased transmission speeds. These increased speeds enable the passing of more information over the communications links, independent of whether the system

used packet switching, multiplexing, or data compression techniques. This would mean that the telephone system could be used for more than simple voice communications.

F. EASE OF RECONFIGURATION

This category may well be the most difficult to determine and evaluate of any of the factors so far discussed. Ease of reconfiguration refers to the ability of a system to adjust to major component failures or outages, and at the same time continue to carry out its specified mission. These major components could be nodes, links, or major components within the nodes or links.[Ref. 6: p. 77] One measure of the ease to reconfigure is defined as the average number of multiple delivery paths to all nodes, including hot standby equipment on the links and nodes, as alternate communications paths. The two systems would be examined in comparison to the average number of multiple paths between nodes as a measure of the ease in which the systems can be reconfigured.

A second method of measuring the ease of reconfiguration is the elapsed time estimating procedure. This estimating procedure measures the average time necessary for the communications control apparatus to modify the system to meet a new traffic need. The measurement requires that the initial traffic need be specified along with an initial system configuration. It also requires the

new estimated traffic need for the system. The measurement consists of measuring the system modification time for each new traffic level that is needed to be handled by the system. The measurement can be done by utilizing PERT charts, where by the replacements of modules would be events, and communications control procedures would be described by the PERT chart structure as activities.[Ref. 6: p.76]

Another method of measuring the ease of reconfiguration is the uniformity estimating procedure. This estimate measures the variances in the way similar modules are utilized in the system. A system configuration which uses the same module in the same way throughout the system is considered flexible, because there are enough modules of differing capacity sizes to meet each local traffic node's needs. The values for this estimate are the average percentage of unused traffic capacity for the n^{th} module of equipment.[Ref. 6: pp. 76-77]

The above methods are not the only methods to measure the ease of reconfiguration criterion, nor may they be the best, but they are possible methods. The user must select the measurement criteria to be used, and determine the method in which to measure this criteria. However, the user must be careful that they and the decision-maker are comfortable with the measure and its use.

AD-A171 725 A METHODOLOGY TO AID THE COAST GUARD IN THE DECISION TO PROCURE OR MAINTAIN TELECOMMUNICATIONS SYSTEMS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA M D INMAN 20 JUN 86 2/2

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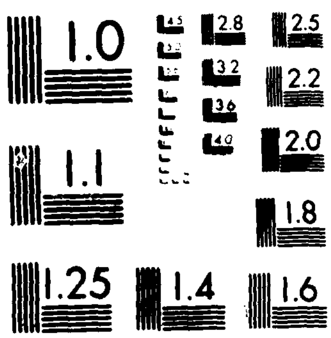


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

G. ADDITIONAL AND ALTERNATE MEASURES

As mentioned earlier, the measures that have been outlined here are not exhaustive. The determination of the measures to be used is dependent on the systems that are being examined and the Coast Guard personnel that are involved in the evaluation process. This is due in part to the fact that Coast Guard personnel and decision makers priorities vary because of geographic concerns, personalities, different organizational structures, etc.. Therefore, for each examination of systems the appropriate performance and capability measure and how to determine or estimate them must be left to those involved in the evaluation.

We have examined the system cost and non-cost factors, as they relate to the spreadsheets that were developed to carry out the evaluation of the two systems. It is now necessary to carry out the comparisons of the systems in order to determine if to maintain the present system or procure a new system. This will be discussed in the following chapter, with a demonstration of the computer software that is utilized.

These verbal ratings are then converted to the numeric values for entry into the pairwise comparison matrix as discussed in the Appendix. Expert Choice provides a user menu that makes the use of the software fairly easy, after an initial training/review of the provided tutorial which takes less then an hour (as experienced by the author). The Expert Choice menu makes it simple to build the hierarchy, carry out the required pairwise comparisons, and by the use of the synthesis command, automatically carry out all required mathematics to obtain the completed solution and the consistency ratio of the users overall judgments.

B. DECISION MODEL HIERARCHY

The first step in developing a solution for a decision problem using the Analytic Hierarchy Process is the analyzing of the problem. Then it is necessary to develop a structure for the hierarchy of the problem. This is done by determining those criteria that are of interest and considered important, and whether the problem requires multiple levels to reach a realistic and reasonable solution.

In the case of determining whether to maintain the present system or procure a replacement system, the criteria that should be integrated into the hierarchy are the performance/capability measures that were listed on the system comparison spreadsheet. From the analysis of this

V. DECISION METHODOLOGY

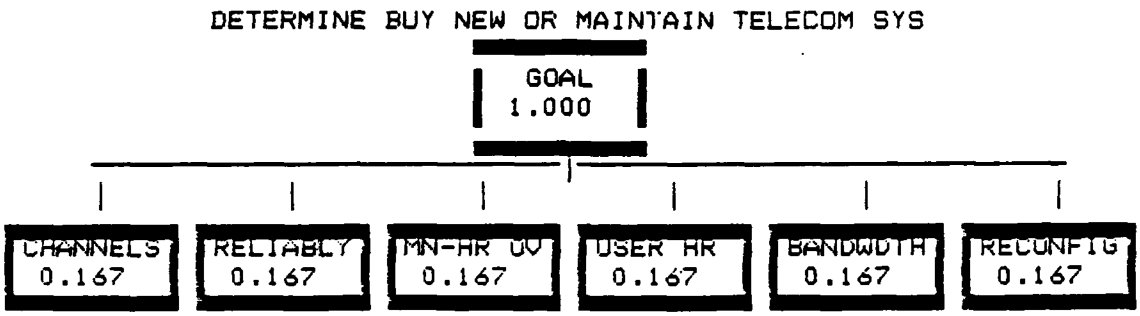
In this chapter the decision methodology will be developed. This decision methodology uses the decision-maker's subjective judgments of the relative importance of the various criteria. This decision methodology will use the Analytic Hierarchy Process (see Appendix). The Analytic Hierarchy Process has been incorporated into computer software by Decision Support Services (DSS) of McLean, Virginia, under the product name of Expert Choice. For this examination Expert Choice serial number BE-SA5083 was used to develop and examine the decision methodology.

A. EXPERT CHOICE, THE BASICS

Expert Choice assists the decision-maker in the solving of complex problems that involve numerous criteria. As with the analytic hierarchy process, the solutions that are developed represent the expertise/opinions of the decision-maker, not that of the computer.

The decision-maker provides judgments about the relative importance of criteria, and his/her preference for the possible alternatives, relative to the respective criteria. Expert Choice gives the decision-maker the ability of entering judgments in a verbal mode, such as criteria A is strongly more important then criteria B.

decision problem, it is felt that only a single level of criteria is required to obtain an efficient solution to this problem. To build the hierarchy using Expert Choice, the user enters Expert Choice, invokes the application command, and enters the name of the application, say TELECOM. The software then asks if the application is a new one, answer yes or no. If the application is a new one, which assuming TELECOM is, Expert Choice asks for the goal to be entered, i.e. determine buy new or maintain telecom sys. The goal node of the hierarchy now appears on the screen. The editing command is then used to finish developing the structure of the hierarchy. The user invokes the edit command, and to insert the level 1 criteria, invokes the insert subcommand. The next step is to type in the first criteria, strike the return key, and continue entering the criteria. When all the level one criteria are entered the user then depresses the <esc> key. The screen displays the goal level and level 1 containing the criteria. Such as the one in figure 5.1 from the system comparison spreadsheet.



Where;

Channels = Communications Channels

Reliably = System Reliability

MN-HR OV = Man-Hours in Overhead

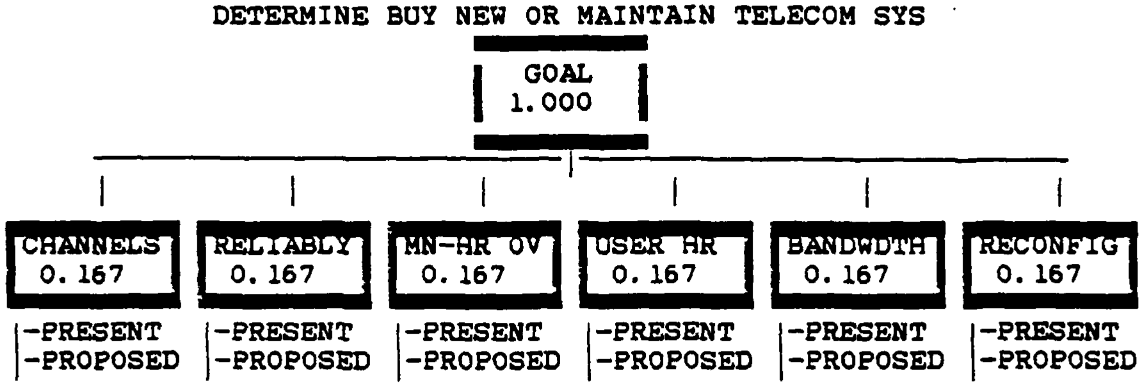
User Hr = Savings in User Man-Hours

Bandwdth = Bandwidth

Reconfig = Ease of Reconfiguration

Figure 5.1. Level 1 Criteria

The next step in the development of the hierarchy is to include the possible solutions, under each of the criteria. This is again done by the use of the edit command, and insert subcommand. Also a possible subcommand for inserting the solutions is the replicate subcommand, which copies the structure under one criteria to all other criteria. Figure 5.2 shows how the completed hierarchy looks.



Where;

Present = Presently Installed System

Proposed = Proposed System.

Figure 5.2. Complete Hierarchy

C. PAIRWISE COMPARISON/ESTABLISHING PRIORITIES

1. Establishment of Criteria Priorities

To develop the priorities for each level from the analytic hierarchy process, requires in Expert Choice the invoking of the compare command. The compare command will then query the type of comparison that is desired: Importance, Preference, or Likelihood. In the evaluation of the maintain/procure decision, for the criteria level, the importance comparison mode would be used. After the invoking of the comparison mode, i.e. importance, Expert

Choice then initiates the pairwise comparison of the goal's branch nodes, in this case the performance/capability measures. The software starts each pairwise comparison with the question of whether the two criteria are equally important and if they are, the software goes to the next comparison. If the criteria are not equally important, it asks if one criteria is more important than the other. Upon answering this question the screen would look similar to that in Figure 5.3.

```
GOAL: DETERMINE BUY NEW OR MAINTAIN TELECOM SYS

                 With respect to
GOAL TO DETERMINE BUY NEW OR MAINTAIN TELECOM SYS

      BANDWDTH
           is MODERATELY MORE IMPORTANT THAN
      USER HR

      +------------------------------------+
      | EXTREME------------                |
      | VERY STRONG--------                |
      | STRONG-------------                |
      | MODERATE-----------  <--           |
      | EQUAL--------------                |
      +------------------------------------+

TO SELECT, ┘ TO ENTER COMPARISON.  MOVE BELOW EQUAL OR 'I' TO INVERT
                  - TO MOVE TO PREVIOUS COMPARISON
* TO CALCULATE/EXIT. <Esc> TO EXIT WITHOUT CALCULATING. N FOR NUMERICAL MODE.
```

Figure 5.3. Verbal Comparison Display

The user answers this by moving the cursor to the level (verbal response) that matches their subjective judgment of

the comparison of the two criteria, and then depresses the return key.

In the case of the evaluation of the two telecommunications systems, the subjective judgments for the criteria would represent the relative importance of the various performance/capability criteria of the systems in the eyes of the decision-maker. The above process is repeated until the pairwise comparison matrix is completed at the level

The user has the option if desired, to provide the judgments in a numeric mode to the priority matrix, by the use of the numeric subcommand. The judgments in this mode would be entered and displayed numerically, as in Figure 5.4.

GOAL: DETERMINE BUY NEW OR MAINTAIN TELECOM SYS
With respect to
GOAL TO DETERMINE BUY NEW OR MAINTAIN TELECOM SYS

CHANNELS is
4.0 TIMES (MODERATE to STRONGLY) MORE IMPORTANT THAN
RELIABLY

9 EXTREME
7 VERY STRONG
5 STRONG
3 MODERATE
1 EQUAL

	CHANNELS	RELIABLY	MN-HR OV	USER HR	BANDWDTH	RECONFIG
CHANNELS		4.0<	4.0	5.0	4.0	5.0
RELIABLY			5.0	7.0	5.0	4.0
MN-HR OV				4.0	4.0	4.0
USER HR					3.0	3.0
BANDWDTH						4.0
RECONFIG						

ENTER 1.0, 1.1, ... ,2.0, ..., 9.0 FOR COMPARISON (PRECEED WITH I IF INVERSE)
or TO MOVE TO OTHER COMPARISONS, or
* TO CALCULATE/EXIT, <Esc> TO EXIT WITHOUT CALCULATING, V FOR VERBAL MODE

Figure 5.4. Numeric Comparison Display

The user would actually fill in the priority establishing matrix as described in the Appendix. The screen display in this mode also shows the verbal judgment that is related to the numeric entry, and the appropriate ranking scale. No matter which method is used to enter the subjective judgments the same methodology is being utilized.

Once the judgments at this level are completed, Expert Choice will automatically calculate the relative weights (priorities) for each criterion, and then display them in a bar chart. Expert Choice will also display the inconsistency ratio (see Appendix) of the judgments for the criterion priorities. An example of these judgments for the criterion relative to the procure/maintain decision are shown by Figures 5.5 and 5.6.

DETERMINE BUY NEW OR MAINTAIN TELECOM SYS
TALLY FOR LEVEL 1 NODES

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
CHANNELS =0.410				
RELIABLY =0.280				
MN-HR OV =0.140				
BANDWDTH =0.084				
RECONFIG =0.052				
USER HR =0.034				

Figure 5.5. Tallying of Criteria

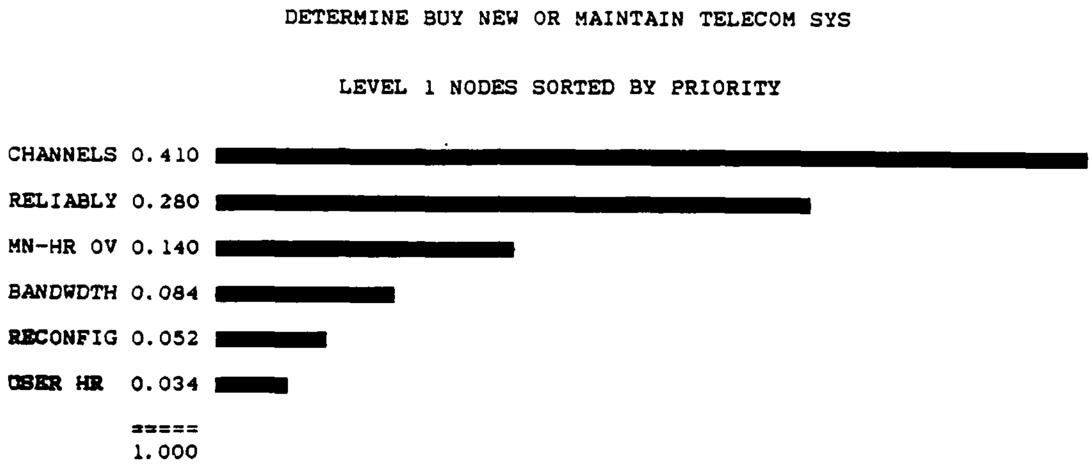


Figure 5.6. Bar Graphs for Tallying of Criteria

2. Establishment of Solution Preferences

Once the priorities have been established for the various criteria. The next step is to compare the possible solutions with respect to each of the criteria. If more then two solutions are outlined/possible Expert Choice will go through the same pairwise comparison procedure as it did

for the criteria level. If on the other hand, there are only two possible solutions, Expert Choice will display two bar charts, i.e. present and proposed, such as shown by Figure 5.7.

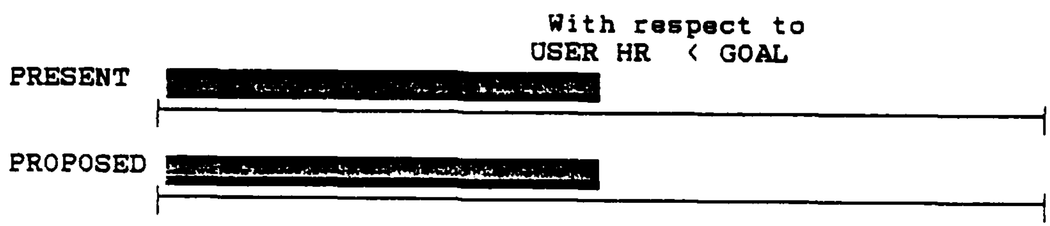


Figure 5.7. Comparison Bar Graphs

The decision-maker would then input a preference for one system over the other, based on the information provided by the system comparison spreadsheet. This is done by adjusting the bar charts through the use of the cursor, until the level of preference of one system over the other for a particular criteria is established, such as displayed by Figure 5.8.

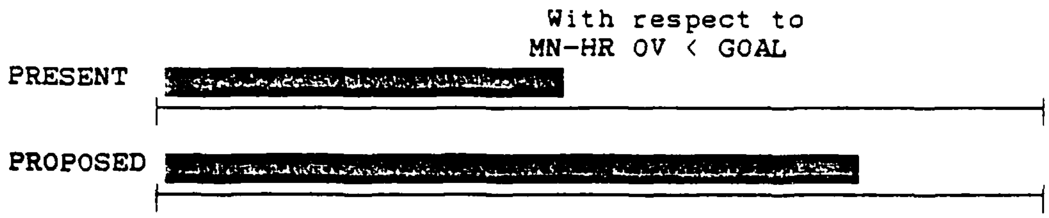


Figure 5.8. Adjusted Comparison Bar Graphs

The user of the software depresses the * (calculate) key, and the software calculates the priorities and display them. If the user is not comfortable with these priorities, they can reenter the compare mode and adjust the preferences until they are comfortable with them. This procedure is repeated for all the respective criteria.

The user, in order to determine the most preferred system, would carefully examine the information provided by the system comparison spreadsheet. After examining this information, the user should have a reasonable idea which system is preferred.

D. THE DECISION PROBLEM SOLUTION

The final step in this methodology is the determining which solution is the proper one. The choices as outlined initially are either to maintain the present telecommunications system, or to procure a replacement

system. After the problem has been quantified, by the development of the necessary decision hierarchy. And the necessary comparisons have been carried out. All that is left is to carry out the mathematical manipulations.

In Expert Choice, the overall decision to the problem of interest is carried out by a process called synthesis. This process involves the calculating for each alternative, the sum of the global priorities over all the criteria. This process is started by the invoking of the synthesize command. The software will query the user for several responses and then will carry out this process automatically, utilizing the information provided. The software will display a tallying of the probabilities as entered by the user/decision-maker, as shown by Figure 5.9. It will then provide bar graphs showing the preference of one system over the other, as shown by Figure 5.10.

DETERMINE BUY NEW OR MAINTAIN TELECOM SYS
TALLY FOR LEAF NODES

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
CHANNELS =0.410				
.	PROPOSED =0.311			
.	PRESENT =0.098			
RELIABLY =0.280				
.	PROPOSED =0.210			
.	PRESENT =0.070			
MN-HR OV =0.140				
.	PROPOSED =0.089			
.	PRESENT =0.051			
BANDWDTH =0.084				
.	PROPOSED =0.046			
.	PRESENT =0.038			
RECONFIG =0.052				
.	PROPOSED =0.051			
.	PRESENT =0.001			
USER HR =0.034				
.	PROPOSED =0.020			
.	PRESENT =0.014			

Figure 5.9. Tallying of System Probabilities

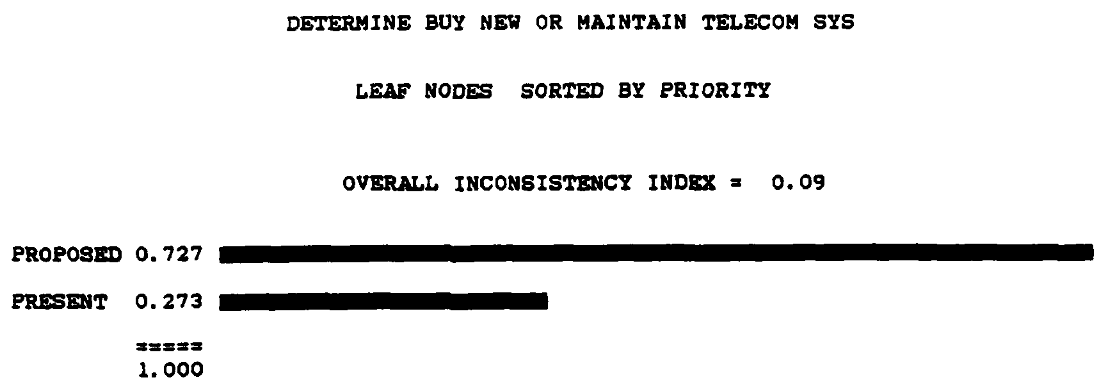


Figure 5.10. System Preference Bar Graphs

The display will also show the overall inconsistency index (as outline in the Appendix) for the comparisons that have been carried out.

The information provided should represent the final solution to the decision problem of maintaining the present telecommunications system, or procuring a replacement system which meets the developed specifications.

E. SENSITIVITY ANALYSIS

Many times it is desirable to determine how sensitive the solution is to changes in the decision criteria that were used. In the case of the maintain/procure decision problem, any sensitivity analysis that would be carried out should involve the performance/capability criteria. In Expert Choice, one way to carry out sensitivity analysis is

by the use of the "what if" subcommand, under the "compare" command function. The "what if" function allows the user to graphically adjust the priorities of the respective criteria or use the numerical mode to adjust the criteria. Then by depressing the * key, Expert Choice will calculate the revised priorities, and display them. This can be repeated as often as the user desires. This analysis will give the user the ability to determine how sensitive the preferred solution is to variations in the probabilities of the respective decision criteria. If the preferred solution changes for small changes in the probabilities of the respective criteria, the user would have to carefully reevaluate his/her preferences/weighting for each criteria.

We have now completely examined the methodology for determining whether to maintain the present telecommunications system or procure a new telecommunications system. The next chapter will summarized the methodology, and present the author's conclusions.

VI. SUMMARY AND CONCLUSIONS

A. SUMMARY

1. The Goal

The author feels that the Coast Guard presently procures too many telecommunications systems without the benefit of a thorough analysis. Any such analysis should examine the benefits that a procured system would provide, and the respective costs. In addition, many times the decision-makers examining the possible procurement of new systems tend to focus on only one measure, such as life cycle cost. At the same time, the author feels that the Coast Guard can not afford to operate at the leading edge of technology. Therefore, the goal of this thesis has been the development of an aid to Coast Guard decision-makers in the determination of whether to procure a new telecommunications system or maintain a present telecommunications system .

2. Methodology

The methodology that has been developed is based on the cost effectiveness of moving from the present system to a proposed new system. The analysis that is carried out results in ratios of the marginal benefits compared against the marginal costs, were the marginal benefits are expressed in non-monetary terms such as the number of communications channels, the mean time between failures, etc. The

decision-maker will then examine these ratios with respect to each of the criteria (i.e. the performance/capability measures), and determine his subjective judgments as to whether he is willing to pay the additional cost that will be incurred for the increases in the performance/capability that would be experienced with the new system. Since multiple criteria are examined the decision-maker must consider simultaneously the respective marginal benefit/marginal cost ratios to determine the preferred system with respect to each of the criteria. He must also determine the importance of each of the respective criteria when compared to the others.

In order to carry out the above analysis a decision aid such as Expert Choice can be constructed or used that enables the decision-maker to integrate effectively the information that is provided (i.e. marginal cost/marginal benefit ratios) with his/her subjective judgments for the preferences for the various criteria.

3. Outline of Thesis Development

In order to develop the methodology as described above, several steps were necessary. The first step was the development of system cost spreadsheets for both the present and proposed systems. These spreadsheets include the cost categories that are considered important, and the final result of each is its life cycle cost. The next step was the development of a spreadsheet that enables the comparison

of the two systems. The system comparison spreadsheet takes the life cycle costs of both systems, and the values for the performance/capability measures for the systems, and combines them to obtain the average costs for each system and the marginal benefit/marginal costs ratios for the move from the present system to the proposed system. The design of the above spreadsheets was discussed in detail in Chapter II. Chapter III and IV detail the computations required to determine the values for the respective cost categories and performance measures.

The final step in the development of the methodology was the integration of the marginal benefit/marginal cost ratio information with the subjective judgments of the decision-maker. This is done by the use of the Analytic Hierarchy Process, which enables the decision-maker to examine the various criteria and determine the relative importance of these criteria. The process gives the decision-maker the ability to examine the marginal benefit/marginal cost ratios and then determine his preference of one system over the other with respect to each criteria. The final result is a recommendation for the preferred system. The Analytic Hierarchy Process was used as implemented by the commercially available Expert Choice software, and was discussed in chapter V and Appendix A.

B. CONCLUSIONS

It is felt that the marginal analysis methods that have been discussed and integrated into the methodology provide a useful framework for solving the decision problem to maintain the present system or to procure a new (replacement) system. This decision problem is truly multidimensional, as many marginal quantities must be considered simultaneously. The integration of the marginal analysis information with the subjective judgments of the decision-maker is possible using "off the shelf" software. The methodology that has been developed is a reasonable specification that can, and should, be turned into a usable decision aid. It should take the form of a single user-friendly software package.

APPENDIX

ANALYTIC HIERARCHY PROCESS

A. INTRODUCTION

In this thesis the Analytic Hierarchy Process will be utilized to aid the decision maker in making the decision. There are in today's problem solving environment two fundamental approach techniques: the deductive approach and the systems approach. "The deductive approach focuses on the parts whereas the systems approach concentrates on the workings of the whole"[Ref. 7: p. 13]. The Analytic Hierarchy Process technique attempts to integrate both into a single logical framework. This framework is designed hopefully to enable the decision maker, and the organization, to deal with complex processes.[Ref. 7: p. 13]

B. BASIC PRINCIPLES

The Analytic Hierarchy Process solves problems by an explicit logical analysis involving three basic principles. These basic principles are: (1) the structuring of hierarchies; (2) the establishment of priorities; and (3) logical consistency.[Ref. 7: p. 17]

1. Structuring Hierarchies

Human beings have the innate "ability to perceive things and ideas, and to then identify them, and communicate

what they observe"[Ref. 7: p. 17]. The mind, in order to retain this detailed knowledge, structures complex reality into its constituent parts, and these in turn into their parts, i.e. a hierarchy. Research has shown that the number of parts that normally exists is between five and nine. "By breaking down reality into homogeneous clusters and subdividing these clusters into smaller ones", humans can integrate larger amounts of "information into the structure of a problem and form a more complete picture of the whole system".[Ref. 7: p. 17]

2. Setting Priorities

Humans also have the ability to perceive differences among the items that are observed in the environment, and to compare pairs of similar items, within certain established criteria, and discriminate between the members of a pair by judging the intensity of their preference for one item over the other. Then by synthesizing their judgments obtaining a better understanding of the whole system. This pairwise comparison enables the establishment of the impact of elements of one level, on each element of the higher level within the hierarchy.[Ref. 7: p. 17]

3. Logical Consistency

The third principle of analytic thought is logical consistency. Humans have the ability to establish the relationship that objects or ideas have with each other in

such a way that they are coherent. In doing this the objects/ideas relate to each other, and their relationship exhibits consistency. Consistency means, first that "similar ideas or objects are grouped according to homogeneity and relevance"[Ref. 7: p. 18]. For example baseballs and bowling balls can be grouped into a homogeneous set if roundness is the relevant criterion, but not if size is the relevant criterion. "The second meaning of consistency is that the intensities of relations among ideas or objects based on a particular criterion justify each other in some logical way". As an example, "if sweetness is the criterion and honey is judged to be five times sweeter that sugar, and sugar twice as sweet as molasses, then honey should be taken as ten times sweeter than molasses"[Ref. 7: p. 18]. Honey being ten times sweeter that molasses would only be true if absolute consistency is shown.[Ref. 7: p. 18]

C. THE BASICS OF THE ANALYTIC HIERARCHY PROCESS

The basic observations of human nature, analytic thinking, and measurement led to the development of the Analytic Hierarchy Process, which is presumed to be a useful model for solving problems.

> The Analytic Hierarchy Process is a flexible model that allows individuals or groups to shape ideas and define problems by making their own assumptions and deriving the desired solution from them[Ref. 7: p. 22].

The process is "designed to accommodate human nature rather than forcing the use of a mode of thinking that might violate" human judgment[Ref 7: p.22]. The Analytic Hierarchy Process incorporates judgments and personnel values in a logical way. It depends on imagination, experience, and knowledge to structure the hierarchy of a problem and use logic, intuition, and experience to provide judgments. Once accepted and followed, "the Analytic Hierarchy Process shows how to connect elements of one part of the problem with those of another to obtain the combined outcome. It is a process for identifying, understanding and assessing the interactions of a system as a whole".[Ref. 7: p. 22]

The overall advantages of the Analytic Hierarchy Process can be summed by Figure A.1. The Analytic Hierarchy Process "is a process of "systemic rationality": in that it enables the consideration of a problem as a whole and to study the simultaneous interactions of its components within the hierarchy".[Ref. 7: p. 24] By the use of the Analytic Hierarchy Process you should gain the following:

1. A practical way to deal quantitatively with different kinds of functional relations in a complex network.

2. A powerful tool for integrating forward (projected) and backward (desired) planning in an interactive manner that reflects the judgments of all relevant managerial personnel. The output of this process is explicit rules for allocating resources among current and new strategy offerings-or to satisfy a specific set of corporate objectives-or under alternative environmental scenarios.

3. A new way to
   - Integrate hard data with subjective judgments about intangible factors.
   - Incorporate judgments of several people and resolve conflict among them.
   - Perform sensitivity analysis and revision at low cost.
   - Use marginal as well as average priorities to guide allocation.
   - Enhance the capacity of management to make tradeoffs explicitly.

4. A technique complementing other ones (benefit/cost, priority, risk minimization) for selecting projects or activities.

5. A single replacement for a variety of schemes for projecting the future and protecting against risk and uncertainty.

6. A vehicle for monitoring and guiding organizational performance toward a dynamic set of goals.

[Ref. 7: p. 25]

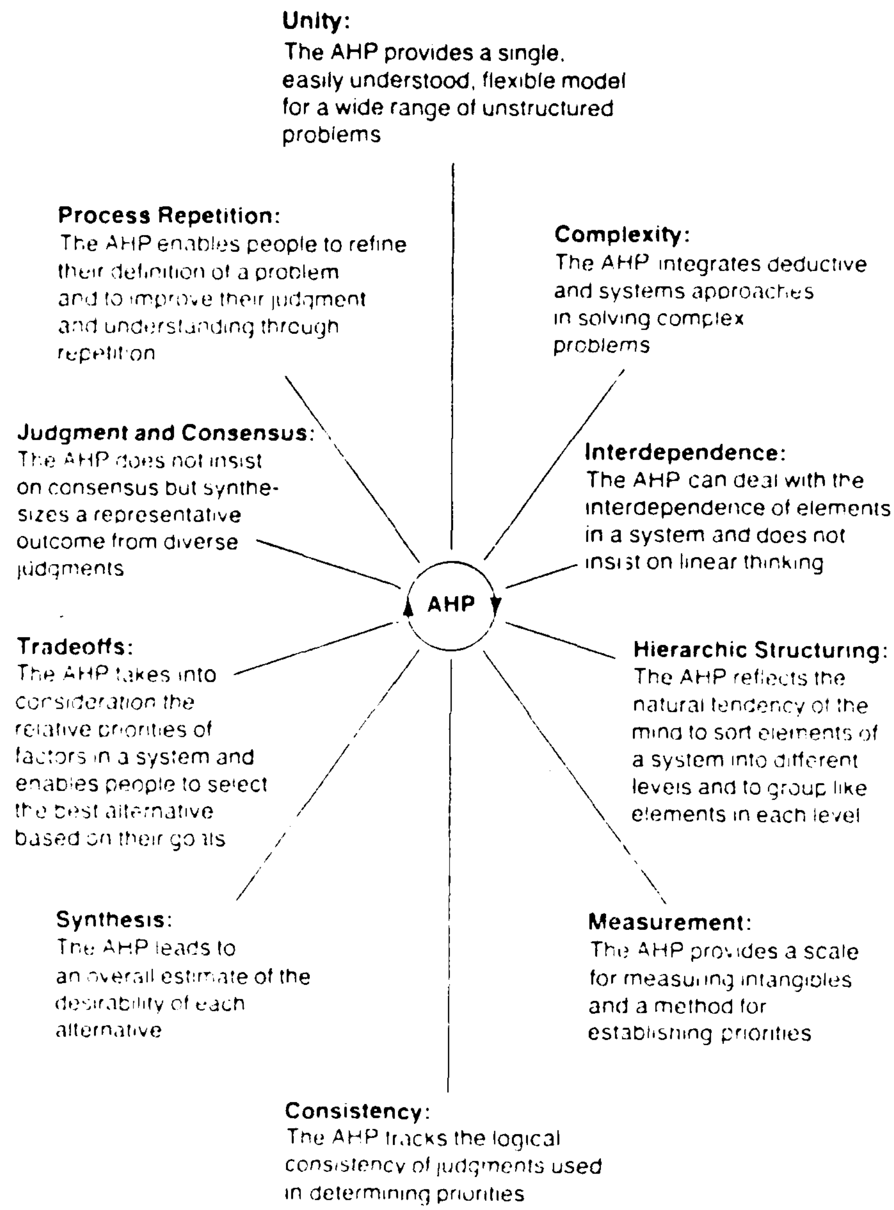


Figure A.1. Advantages of the Analytic Hierarchy Process.

[Ref. 7: p. 23]

D. ANALYZING AND STRUCTURING HIERARCHIES

One useful way to understand complex systems is by breaking them down into constituent elements, then structuring the elements hierarchically. The next step is to compose, or synthesize, judgments on the relative importance of the elements at each level of the hierarchy into a set of overall priorities.

1. Classifying Hierarchies

There are basically two types of hierarchies, structured and functional. Structural hierarchies are those complex systems that are organized into the constituent parts in descending order according to structural properties, such as shape, size, color, age.

> This type of hierarchy relates closely to the way the brain analyzes complexity by breaking down the objects perceived by human senses into clusters, sub-clusters, and still smaller clusters.[Ref. 7: p. 28]

"Functional hierarchies decompose complex systems into their constituent parts according to essential relationships", such as objectives of the major stakeholder(s) in a system[Ref. 7: p. 28]. In the functional hierarchy a set of elements occupies a level of the hierarchy. The top level, called the focus, consists of only one element, which is the broad, overall objective. The subsequent levels may each have several elements, normally between 5 and 9. Because the elements at each level must be compared to each other with respect to the

criteria of the level immediately above. all the elements at one level must be of the same magnitude.[Ref. 7: pp. 28-29]

2. Constructing The Hierarchy

When constructing the hierarchy for the system that is to be analyzed or examined, there exist no inviolable rules. A possible approach to "constructing a hierarchy depends on the kind of decision to be made. If it is a matter of choosing among alternatives. Building the hierarchy could start at the bottom level listing the possible alternatives. The next level would then consist of the criteria for judging the alternatives"[Ref. 7: p. 30]. This upward flow would then continue until the top level is reached which would consist of a single element, the focus or overall purpose for which the hierarchy is being used. The top level would be the desired goal, to which the lower level elements would be compared. These comparisons would be carried out to determine each lower level element's contribution to the obtaining of the overall goal.[Ref. 7: pp. 29-30]

An example of a hierarchy that might be used for deciding which sports car to purchase is shown by Figure A.2.

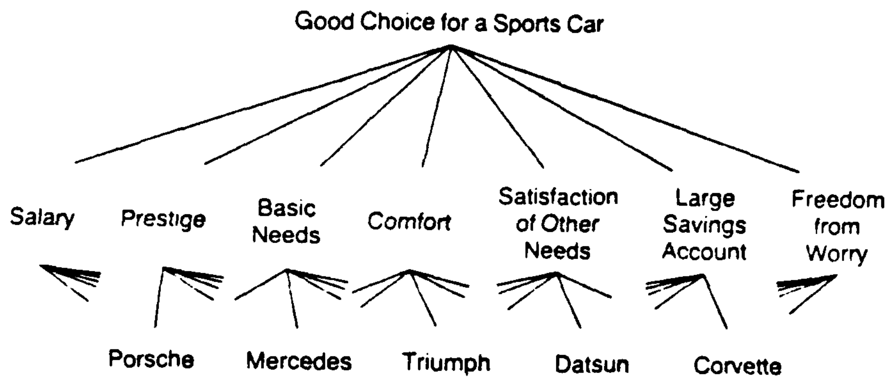


Figure A.2. Hierarchy for Choosing a Sports Car [Ref. 7: p. 30]

E. ESTABLISHING PRIORITIES

In this section, The author will attempt to show, in fairly basic and non-complicated terms, the way in which priorities are established within the Analytic Hierarchy Process, and to examine how consistency relates to these priorities, and why it is important.

1. Setting Priorities

It has been pointed out that complex relationships can always be analyzed by taking pairs of elements from the hierarchy, and relating them through their attributes. This causal approach to understanding complexity is complemented

by the systems approach, which has the objective of finding the subsystems or dimensions in which the parts are connected. Systems thinking is addressed by structuring ideas hierarchically. Causal thinking, or exploration, is developed through paired comparison of the elements in the hierarchy and through synthesis.[Ref. 7: p. 76]

In order to establish the priorities of elements in a decision problem (or other problems that utilize the Analytic Hierarchy Process), pairwise comparisons must be used. This entails comparing the elements in pairs against a given criteria. For pairwise comparison, a matrix is the preferred form to carry out the desired comparisons. The author assumes that the reader has some familiarity with matrices.[Ref. 7: p. 77]

The priority setting method can be described by the following: "Given the elements of one level, say, the fourth of a hierarchy and one element, E of the next higher level, compare the elements of level 4 pairwise in their strength of influence on E. Insert the agreed upon number, reflecting the comparison, in a matrix and find the eigenvector with the largest eigenvalue. The eigenvector provides the priority ordering, and the eigenvalue is a measure of the consistency of the recorded judgments".[Ref. 8: p. 17]

When comparing elements, we are attempting to determine how much is one element preferred, more important

than, or more likely to occur then another element. When comparing elements the phrasing of the question is important. It must reflect the proper relationship between the elements in one level with the property in the next higher level. Experience and the comprehension abilities of humans has confirmed that a scale of nine units is reasonable for use, and reflects the degree to which humans can discriminate the intensity of relationships between elements. The scale and word phases that can be used if verbal judgments are desired is listed in table II.[Ref. 7: pp. 77-78]

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Weak importance of one element over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment strongly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	Compromise is needed between two judgments
Reciprocals	If activity *i* has one of the preceding numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Table II. The Pairwise Comparison Scale

[Ref. 7: p. 78]

To show how to determine the priorities of the elements at one level, the following demonstration will be used. Let the elements of a level be A,B,C,D. At this point it is not really important to know what these elements stand for, since the area of interest is the mathematics involved in the determination of the priorities. The number for the comparisons described and the judgments will be entered into a matrix. By convention, the comparison of strength is always of an activity appearing in the column on the left against an activity appearing in the row on top. Therefore, the pairwise comparison matrix has four rows and four columns (a 4X4 matrix) for this demonstration as in Figure A.3.

	A	B	C	D
A				
B				
C				
D				

Figure A.3. Sample Matrix Form

The pairwise comparison is carried out using the 9 level scale discussed earlier, where if A is strongly more important then B, then the element in the row A ,column B position in the matrix has a value of 5. As an element is equally important when compared with itself, the main diagonal of the matrix will have 1's as the values entered. And normally the element in the row B, column A position of

the matrix would have the reciprocal of the element in row A, column B, i.e. if AB = 5, BA = 1/5.

For this demonstration there are sixteen spaces in the matrix to fill in. Of these, the four on the main diagonal are predetermined. Their value is set to unity (1). Of the remaining twelve numbers, six need to be filled in, because the other six will be the reverse comparisons and must be reciprocals of the first six. After the six required judgments are made, in this case A to B, A to C, A to D, B to C, B to D, and C to D, the matrix may look as Figure A.4:

	A	B	C	D
A	1	5	6	7
B	1/5	1	4	6
C	1/6	1/4	1	4
D	1/7	1/6	1/4	1

Figure A.4. Sample Comparison Matrix
[Ref. 8: p. 19]

The next step consists of the computation of the vector of priorities. The principle eigenvector is computed and then normalized. This normalized eigenvector represents the priority vector. For Figure A.4, the normalized vector is (0.61, 0.24, 0.10, 0.05). The exact solution (normally carried out by computers) to the problem would be obtained by raising the matrix to arbitrarily large powers and dividing the sum of each row by the sum of the elements of

the matrix. If computer software is absent, these matrices can be crudely solved by hand as outline by Saaty.[Ref. 8: pp. 17-20]

Where there are multiple levels within a hierarchy, the above process must be carried out at each level. This as was displayed above for Figure A.4, where the pairwise comparisons were carried out, and a priority vector was determined by normalizing the principle eigenvector. At each level a normalized eigenvector is determined, which acts as the priority vector with respect to the level directly above. Then the process is to determine the interrelationships between the levels. The determination of the interrelationships between levels is done by coming down the hierarchy weighting each vector by the priority of the level above. This is carried out by matrix multiplication of the priorities between levels. This synthesis results in a set of net priority weights for the bottom level (solution alternatives) of the hierarchy.[Ref. 8: pp. 20-28]

For an example of the above process, the matrix in Figure A.4 will be considered level 1 of the hierarchy (i.e. one level below the goal node). The variables A, B, C, and D will be considered possible selection criteria, and the priority vector for this level will be represented by (a, b, c, d). We will then assume that we have the three variables E, F, and G, at the next level for all the level 1 criteria. E, F, and G will be considered possible alternatives. The

goal then is to determine the net priority weights for E, F, and G. In order to do this the first step would be to carry out the pairwise comparisons of E, F, and G with respect to each criteria (i.e. A, B, C, and D), and then determine the normalized eigenvector for E, F, and G for each of the selection criteria. This results in the following priority vectors: E, F, and G with respect to A, which will be represented by (e_A, f_A, g_A), with respect to B, which will be represented by (e_B, f_B, g_B), with respect to C, which is represented by (e_C, f_C, g_C), and with respect to D, which will be represented by (e_D, f_D, g_D). These are then placed in a matrix where the columns represent each of the priority vectors. This matrix is then multiplied with the level 1 priority vector (a, b, c, d) as shown in Figure A.5.

$$\begin{vmatrix} e_A & e_B & e_C & e_D \\ f_A & f_B & f_C & f_D \\ g_A & g_B & g_C & g_D \end{vmatrix} \begin{vmatrix} a \\ b \\ c \\ d \end{vmatrix}$$

Where;

e_A = The relative weight of E with respect to A

f_A = The relative weight of F with respect to A

g_A = The relative weight of G with respect to A

.

.

ETC.

Figure A.5. A Sample Matrix Multiplication

The net result of this matrix multiplication is the following:

$$\text{Overall Rank of E} = (e_A)a + (e_B)b + (e_C)c + (e_D)d$$

$$\text{Overall Rank of F} = (f_A)a + (f_B)b + (f_C)c + (f_D)d$$

$$\text{Overall Rank of G} = (g_A)a + (g_B)b + (g_C)c + (g_D)d$$

The overall rankings of the variables E, F, and G is the set of net priority weights for the bottom level.

F. CONSISTENCY

> In decision-making problems it may be important to know how good the consistency is, because we may not want the decision based on judgments that have such low consistency that they appear to be random[Ref. 7: p. 82].

On the other hand, perfect consistency is difficult to impossible to obtain in real life. If baseball team A beats team B, for example, and team B beats team C, than in a perfectly consistent relationship team A must beat team C. This may well not be the case when dealing with real life. The Analytic Hierarchy Process measures the overall consistency of judgments made by the means of a consistency ratio. The value of the consistency ratio should be 10 percent or less. If more than 10 percent, the initial judgments may be some what random and may well require revising.

In order to show how the consistency of a level of the hierarchy is determined, the following example is provided: We first take the comparison matrix (i.e. Figure A.4) with

the matrix changed to decimal form, and multiple each column by its respective priority from the priority vector (i.e. column A by 0.61, column B by 0.24, etc.) This results in the matrix shown in Figure A.6, which includes the summation of each row.

	A	B	C	D	ROW TOTAL
A	0.61	1.20	0.60	0.35	2.76
B	0.122	0.24	0.40	0.03	1.062
C	0.102	0.06	0.10	0.20	0.462
D	0.087	0.04	0.025	0.05	0.202

Figure A.6. Inconsistency Determination Matrix

The procedure is then to divide each of the row totals by its corresponding entry from the priority vector:

$$\begin{vmatrix} 2.760 \\ 1.062 \\ 0.462 \\ 0.202 \end{vmatrix} \div \begin{vmatrix} 0.61 \\ 0.24 \\ 0.10 \\ 0.05 \end{vmatrix} = \begin{vmatrix} 4.524 \\ 4.425 \\ 4.620 \\ 4.040 \end{vmatrix}$$

Then it is necessary to find the average of the three entries obtained above;

$$\frac{4.524 + 4.425 + 4.62 + 4.04}{4} = \frac{17.609}{4} \approx 4.40$$

By convention this is λ_{max}. The next step is to determine the consistency index (CI), which is described by the following equation:

$$CI = \frac{\lambda_{max} - N}{(N - 1)}$$

Where N= number of activities in the matrix. In this case N is equal to 4, therefore the derivation looks as follows

$$CI = \frac{4.40 - 4}{3} = \frac{0.40}{3} = 0.1333$$

Next the consistency index of a randomly generated reciprocal matrix for the comparison scale of 1 to 9, with reciprocals forced, which is called the Random Index (RI) is used to determine the consistency ratio. These values are found in the Table III, and were developed by computer manipulation at the Oak Ridge National Laboratory and the Wharton School of Business.

Size of Matrix	1	2	3	4	5	6	7	8	9
Random Index	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Table III. Random Index Matrix

[Ref. 8: p. 21]

The consistency ratio is then represented by the following equation:

$$CR = \frac{CI}{RI}$$

Where RI = Random index.

Therefore the CR for the above example would be: 0.1333/0.90 = 0..148, which indicates some inconsistency. There are other methods of finding the consistency ratio, the above being the simplest and the easiest.[Ref. 7: pp. 82-85]

LIST OF REFERENCES

1. Blanchard, B.S., Logistics Engineering And Management, 3rd ed., Prentice Hall, 1986.

2. Maurice, S.C., and Smithson, C.W., Managerial Economics, 2nd ed., Richard D. Irwin, Inc., 1985.

3. Naval Electronics Laboratory Center Report 1982, A-7 Aloft Life-Cycle Cost And Measures Of Effectiveness Models, by R.A. Greenwell, 1 March 1976.

4. U.S. Defense Communications Agency, Defense Communications Agency, Cost And Planning Factors Manual, DCA CIRCULAR 600-6-1-REV, Arlington, VA., 1983.

5. Joint Tactical Communications Office, Cost Effectiveness Program Plan For Joint Tactical Communications, Volume III Life Cycle Costing, Fort Monmouth, NJ., 1978.

6. Joint Tactical Communications Office, Cost Effectiveness Program Plan For Joint Tactical Communications, Volume II System Effectiveness, Fort Monmouth, NJ., 1978.

7. Saaty, T.L., Decision Making For Leaders, Life Time Learning Publications, 1982.

8. Saaty, T.L., The Analytic Hierarchy Process, McGraw-Hill, Inc., 1980.

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